JOURNAL OF AGRICULTURAL RESEARCH

VOL. XXIX WASHINGTON, D. C., JULY 1, 1924[1] No. 1

SEGREGATION AND CORRELATED INHERITANCE IN CROSSES BETWEEN KOTA AND HARD FEDERATION WHEATS FOR RUST AND DROUGHT RESISTANCE[2]

By J. ALLEN CLARK[3]

Agronomist in Charge, Western Wheat Investigations, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture

RESISTANCE TO RUST AND DROUGHT DESIRED

In the northern spring-wheat area of the United States drought and rust are the principal limiting factors in successful wheat production, and are the causes of enormous losses. Since certain varieties of wheat have been found to possess resistance to these destructive agencies, the problems for further improvement are important to the wheat breeder.

The writer here presents some early studies made in a cross between Kota, a rust-resistant variety of hard red spring wheat, and Hard Federation, a drought-resistant variety of white wheat. The effect of this resistance on yield is of great economic importance. High yield, however, is not the only consideration; the quality of the product is of equal importance to that of yield. A careful study of the milling and baking qualities of the parents and hybrids, therefore, is included in the present work.

MATERIAL AND METHODS

A new variety of hard red spring wheat in order to be successful must yield more than the principal competing commercial variety and be equal or superior to it in milling and baking qualities. The most extensively grown variety of hard red spring wheat at the present time is Marquis. The value of the parents and hybrids in this study, therefore, will be determined in comparison with the Marquis variety.

SELECTING THE PARENTS

Kota and Hard Federation were selected as parents for the cross here discussed because they appeared to supply the best available material for combining in one study the problems of breeding for both rust and drought resistance. The reasons which influenced the selection of the varieties used are their high yielding ability under conditions of rust and drought, and the milling and baking qualities of both varieties. They have several contrasting morphological characters and milling and baking qualities which contribute to their value. The inheritance of these is important.

Both varieties are comparatively new to the farmers of the northern spring-wheat area of the United States. They are new even to the experimental agronomist. Neither has been included in varietal experiments for longer than six years. The writer believes, however, that they have been sufficiently tested to insure their successful commercial production over wide areas as well as their successful use in the mill and bakery. The commercial production of both varieties in the United States began in 1919 and nearly 50,000 acres of each were grown in 1923.

KOTA

Kota is a variety of hard red spring wheat which is resistant to black stem

[1] Beginning with Volume 29, No. 1, the Journal of Agricultural Research will appear semimonthly instead of weekly, the issue dates being the 1st and 15th of each month.

[2] Received for publication Mar. 29, 1924—issued January, 1925.

[3] The writer wishes to express his appreciation to Dr. Sewell Wright, of the Bureau of Animal Industry, and to Dr. H. K. Hayes and Dr. Fred Griffee, both of the Minnesota Agricultural Experiment Station, for advice and assistance given during the collecting and analyzing of the data. To V. H. Florell, at Davis, Calif., Olaf S. Aamodt, at St. Paul, Minn., and J. C. Brinsmade, jr., at Mandan, N. Dak., thanks are here gladly given for assistance in growing the material studied and in taking notes thereon. The writer also desires to acknowledge the services of John R. Hooker for statistical assistance given.

rust. The resistance in this variety was determined independently in 1918 by Waldron and Clark (*36*).[4] The original seed of the variety was obtained in Russia by Prof. H. L. Bolley, of the North Dakota station, in 1903, while making a study of the flax industry of Europe for the United States Department of Agriculture. Previous to 1918 resistance to stem rust of wheat was a quality not known to have been reported among varieties of hard red spring wheat grown in the United States.

Kota has awned, fusiform spikes; glabrous, white, glumes; and midlong, hard red kernels. It is a midtall, midseason spring wheat which has weak to midstrong stems.

For a more complete description of both Kota and Hard Federation, see Clark, Martin and Ball (*6*).

ADAPTATION.—The acre yields of Kota have averaged considerably higher in North Dakota and South Dakota during the past three to five years than those of Marquis, the standard variety of hard red spring wheat. Kota also has produced good yields in the northeastern portions of Montana and Wyoming. It has proved somewhat resistant to drought, as well as distinctly resistant to stem rust, in the northern Great Plains area.

States show that Kota lodges readily, and principally for this reason it yields poorly and is not suited to humid conditions. From central Montana westward, Kota also has not proved to be particularly well adapted. In this intermountain and Pacific coast area varieties of common white wheat, especially Hard Federation, have considerably outyielded both Kota and Marquis.

Kota has been included in experiments at the North Dakota Agricultural Experiment Station near Fargo, N. Dak., for a longer period than elsewhere. Experiments at Mandan and Dickinson also show it to be well adapted to North Dakota. At Moccasin, Mont., however, which is outside of the area affected by stem rust, Kota is not better adapted than Marquis. The yields of Kota and Marquis obtained from replicated plat experiments at these four experiment stations serve to show the adaptation of Kota and are given in Table I, with the average difference in bushels, and per cent, the odds against the difference being due to chance as determined by Student's (*1*) method.

Additional yields and rust data reported by Clark and Waldron (*9*) give more complete information regarding the adaptation of Kota. Table I

TABLE I.—*Annual and average acre yields of Kota and Marquis wheat grown in experiments at four experiment stations during four or more of the six years from 1918 to 1923, inclusive*

Station and variety	Acre yield (bushels)								Odds	Per centage of Marquis
	1918	1919	1920	1921	1922	1923	Average	Difference		
Fargo, N. Dak.:[a]										
Kota	28.4	17.4	22.8	17.8	30.8	29.2	24.4	+4.3	36.5:1	121.4
Marquis	21.5	15.7	12.2	19.4	26.1	25.5	20.1	.....	.....	100.0
Mandan, N. Dak.:[b]										
Kota	.....	.....	9.1	4.4	18.6	14.4	11.6	+1.4	125.6:1	113.7
Marquis	.....	.....	7.4	3.8	16.7	12.9	10.2	.....	.....	100.0
Dickinson, N. Dak.:[c]										
Kota	.....	6.6	22.4	4.2	31.0	21.8	17.2	+2.2	9.1:1	114.7
Marquis	.....	3.4	15.9	5.6	31.6	18.3	15.0	.....	.....	100.0
Moccasin, Mont.:[c]										
Kota	.....	.....	21.0	28.3	26.5	23.8	24.9	−0.9	15.2:1	96.5
Marquis	.....	.....	23.1	28.3	27.3	24.6	25.8	.....	.....	100.0

[a] Experiments conducted independently by the North Dakota Agricultural Experiment Station, the courteous permission to use the results being hereby acknowledged.

[b] Experiments conducted cooperatively by the Offices of Cereal Investigations and Dry-Land Agriculture Investigations of the Bureau of Plant Industry, U. S. Department of Agriculture.

[c] Experiments conducted by the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the State agricultural experiment stations.

In the more humid sections of the spring-wheat region, including Minnesota, Wisconsin, and Iowa, Kota is not well adapted. Experiments in these shows, however, that there is an important and significant difference between the yields of Kota and Marquis at Fargo and Mandan, but decreasing

[4] Reference is made by number (italic) to "Literature cited," p. 46-47.

in significance at Dickinson and westward as damage from rust decreases until at Moccasin, Mont., Kota is slightly outyielded by Marquis.

QUALITY.—Milling and baking experiments conducted in the United States Department of Agriculture from 1918 to 1923, inclusive, show Kota to compare very favorably with Marquis in these respects. In all, 86 samples of the Kota variety, representing five crop years, have been studied. These samples were obtained from experiment stations and commercial sources. The commercial samples do not make possible an accurate comparison with Marquis. At experiment stations, however, the two varieties were grown under exactly the same conditions and comparable samples were obtained for experimental milling.

TABLE II.—*Summary of milling and baking data from 86 samples of Kota wheat and from 60 of these Kota samples and 60 comparable samples of Marquis grown during the five crop years from 1918 to 1922, inclusive* [a]

Descriptive data	All Kota samples	Comparable samples		
		Kota	Marquis	Kota in percentage of Marquis
Number of samples	86	60	60	
Bushel weight ..... pounds	60.3	59.8	57.5	104.0
Crude-protein content of wheat [b] ..... per cent	14.3	14.9	14.2	104.9
Yield of straight flour ..... do	74.2	73.4	71.4	102.8
Yield of shorts ..... do	14.1	14.7	14.2	103.5
Yield of bran ..... do	14.1	14.1	16.5	85.5
Milling gain ..... do	2.4	2.2	2.1	104.8
Water absorption of flour ..... do	64.9	65.5	60.1	109.0
Volume of loaf ..... cubic centimeters	2,242	2,246	2,272	98.9
Weight of loaf ..... grams	512	514	502	102.4
Texture of crumb ..... score	91.4	91.0	89.0	102.2
Color of crumb ..... do	90.1	89.9	90.8	99.0
Ash in flour ..... per cent	[c] 54	[d] 57	[d] 51	111.8

[a] Experiments conducted by the Milling Investigations Section, Grain Division, of the Bureau of Agricultural Economics.
[b] N×15.7, basis 13.5 per cent moisture.
[c] Average of 84 samples.
[d] Average of 58 samples.

Table II shows the average results from the 86 samples of Kota and from 60 comparable samples of Kota and Marquis and the difference between the comparable samples expressed in percentage of Marquis taken as 100 per cent.

The data show Kota to exceed Marquis in most factors. A statistical analysis of these results by Clark and Shollenberger (7) fully discusses the significance of the differences and variability. There are objections to the Kota variety by the trade because of its high ash content and the creamy or yellowish color of its flour. To meet these objections by the grain trade and maintain the good qualities of the variety are a part of the object of this investigation.

HARD FEDERATION

Hard Federation is a variety of white wheat which has proved very resistant to drought. It was developed about 1908 by J. T. Pridham, at the Cowra Experiment Station in New South Wales, Australia, by selection from Federation. It was introduced into the United States by the United States Department of Agriculture in 1915, and was first tested at experiment stations at Moro, Oreg., and Chico, Calif. The success of the experiments was reported by Clark, Stephens, and Florell (8). From these stations seed has since been distributed to farmers.

Hard Federation has awnless, oblong spikes; glabrous, brown glumes; and short, hard, white kernels. It is an early spring wheat which has very strong stems and small leaves that twist or curl. This latter peculiar habit undoubtedly is heritable. It apparently decreases transpiration, which is one cause of the resistance of the variety to drought.

ADAPTATION.—Hard Federation has proved to be the highest yielding variety of spring wheat grown under dryland conditions in Oregon. In California it is grown from fall sowing and is well adapted to some soils. It also has produced excellent yields in central

Montana. In these Pacific coast and intermountain States it often outyields Marquis from 5 to 10 bushels per acre, and it is rapidly becoming an important variety in many of the semiarid sections of the west. It is susceptible to stem rust and does not yield well where this disease is prevalent.

Hard Federation has been included in varietal experiments for a longer period at the Sherman County Substation, Moro, Oreg., than elsewhere in the United States. During the six-year period, from 1918 to 1923, inclusive, in which it has been grown there, the annual precipitation has averaged 11.36 inches. When grown on clean summer fallow under this limited rainfall, Hard Federation has proved a remarkably drought-resistant wheat. Eastward the advantage decreases, although at Moccasin in central Montana it has produced some very favorable yields in dry seasons and when weeds were not abundant. At Dickinson and Mandan, N. Dak., however, where stem rust, as well as drought, has limited the yields of wheat and where weed growth is abundant, Hard Federation has not shown to outstanding advantage. The short stems and curling leaves of Hard Federation render it unadapted for overcoming weed growth. The yields of Hard Federation and Marquis from varietal experiments at Moro, Moccasin, Dickinson, and Mandan, are shown in Table III, together with the differences in bushels, the odds against the occurrence of such a difference being due to chance alone, and the percentage of Hard Federation in terms of Marquis.

Table III shows that there is an important and significant difference in the yield of Hard Federation over Marquis in the drier western sections but the difference decreases in amount and significance eastward.

QUALITY.—Milling and baking experiments have been conducted by the United States Department of Agriculture with Hard Federation wheat during the 5 years from 1918 to 1922, inclusive. In all, 49 samples have been studied. As many as 44 of these can be directly compared with comparable samples of Marquis. Table IV gives a summary of these results.

The data show Hard Federation to compare favorably with Marquis in most factors. For a white wheat it is shown in experiments reported by Shollenberger and Clark (*30*) to be one of the best varieties for breadmaking in its class. It has no important objectionable feature when compared with Marquis, the leading variety for milling and breadmaking. The ash in its flour is low in comparison with Marquis and the color of crumb is high. Partly for these reasons it was selected for crossing with Kota with the hope that selections of the hybrid could be developed which would relieve the objection of the trade to the Kota variety.

TABLE III.—*Annual and average acre yields of Hard Federation and Marquis wheats grown in experiments at four agricultural experiment stations during three or more of the six years from 1918 to 1923, inclusive*

Station and variety	Acre yield (bushels)								Odds	Percentage of Marquis
	1918	1919	1920	1921	1922	1923	Average	Difference		
Moro, Oreg.[a]:										
Hard Federation	21.3	28.7	25.9	29.0	21.0	40.8	27.8	+6.4	4999:1	129.9
Marquis	15.0	22.7	19.2	19.7	17.0	34.9	21.4			100.0
Moccasin, Mont.[a]:										
Hard Federation			30.8	32.1	34.2	[b]17.1	28.6	+2.8	3:1	110.9
Marquis			23.1	28.3	27.3	24.6	25.8			100.0
Dickinson, N. Dak.[a]:										
Hard Federation				3.0	29.7	9.7	14.1	−4.4	10.3:1	76.2
Marquis				5.6	31.6	18.3	18.5			100.0
Mandan, N. Dak.:										
Hard Federation				6.7	18.1	11.1	12.0	+0.9	2.3:1	108.1
Marquis				3.8	16.7	12.9	11.1			100.0

[a] Experiments conducted by the Office of Cereal Investigations of the Bureau of Plant Industry in cooperation with the State agricultural experiment station.
[b] Damaged by hail.

TABLE IV.—*Summary of milling and baking data from 49 samples of Hard Federation wheat and from 44 of these Hard Federation samples and 44 comparable samples of Marquis grown in one or more of the five years from 1918 to 1922, inclusive* [a]

Descriptive data	All Hard Federation samples	Comparable samples		
		Hard Federation	Marquis	Hard Federation in percentage of Marquis
Number of samples	49	44	44	
Bushel weight	59.0	58.8	58.9	99.8
Crude-protein content of wheat [b] per cent	13.5	13.7	14.0	97.9
Yield of straight flour do	71.7	71.6	73.2	97.8
Yield of shorts do	15.2	15.2	14.1	107.8
Yield of bran do	14.3	14.5	14.9	97.3
Water absorption of flour do	63.3	63.2	60.7	104.1
Volume of loaf cc	2,147	2,152	2,211	97.3
Weight of loaf grams	509	509	503	101.2
Texture of crumb per cent	89.7	89.8	88.9	101.0
Color of crumb do	93.0	93.0	91.7	101.4
Ash in flour do	[c] 47.0	[d] 47.0	[d] 51.0	92.2

[a] Experiments conducted by the Milling Investigations Section, Grain Division, of the Bureau of Agricultural Economics.
[b] (N × 15.7, basis 13.5 per cent moisture).
[c] 48 samples.
[d] 43 samples.

METHODS OF STUDY

The Kota × Hard Federation and reciprocal crosses here studied were made at the request of the writer by Florell (*12*) at Chico, Calif., in May, 1920. The F_1 material, which included 82 plants, was harvested by the writer at Chico, Calif., in June, 1921. The material was divided, one head from each plant being retained in California to furnish seed for sowing at Davis, Calif., and the remainder sent to Washington, D. C., for growing, storage, and distribution to other stations. About 450 seeds were grown in the greenhouse at Arlington Experiment Farm, near Washington, D. C., during the winter of 1921–1922, which furnished F_3 material for growing in the field in 1922. A few crosses were made in the greenhouse for furnishing additional F_1 material.

In the spring of 1922 one head from each of the F_1 hybrid plants grown at Chico was sent from Washington to University Farm, St. Paul, Minn., together with small quantities of F_1 and F_2 seed grown in the greenhouse at Arlington. Seed from all of the remaining heads of the F_1 plants, except one from each which was reserved, were sent to Mandan, N. Dak., together with some of the F_2 seed grown in the greenhouse at Arlington.

There was grown, therefore, F_2 material in 1922 at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak. This distribution of the material seemed desirable from both the economic and investigational viewpoints. It carefully guarded against loss of the material and furnished data for study of genetic and environmental influence at three points rather than one. At Davis, Calif., the seed was fall sown and grown under ideal conditions. At St. Paul, Minn., it was grown under conditions artificially insuring rust infection and at Mandan, N. Dak., under usually droughty conditions. In 1922 and 1923 both rust and drought affected the crop somewhat at Mandan.

The seeds from F_1 plants were carefully spaced at all three points to enable the taking of data on individual F_2 plants. Both parents were seeded similarly in check rows together with Marquis. The F_3 material grown in 1922 was not used to complete the inheritance study of the cross, but for advancing material of the cross one year from which to make selections.

In 1923 F_3 selections were grown at Davis, Calif., Mandan, N. Dak., and St. Paul, Minn. In addition a few F_3 selections were grown at Fargo, N. Dak. At Mandan, N. Dak., there also were grown about seventy-five F_4 selections made there the previous season from seed grown in the greenhouse at Arlington. These selections were grown in single 16-foot nursery rows but with different rates of seeding due to the limited and uniform amounts of seed. No yields were obtained from

this nursery, therefore, but further selections were made from it and the most promising homozygous and rust-resistant rows threshed. The grain from twenty-nine of these has been studied in four quality tests in an early effort to determine the quality of the hybrids in comparison with the parents and Marquis.

INHERITANCE OF CHARACTERS

The cross has furnished material for a study of the inheritance of several valuable and interesting plant characters and grain qualities. These characters which have been studied are inheritance of the awn or its absence, color of the glumes, color of the kernels, date of heading, height of plant, resistance to stem-rust infection, and yield. The grain qualities which thus far have been analyzed in the hybrids are crude protein, for the quantity of the gluten; viscosity, for the quality of the gluten; gasoline color test for the color of the flour, and ash determination for the amount of ash in the flour.

As resistance to black stem rust was one of the principal objects of the research, the material grown at University Farm, St. Paul, was artificially inoculated with stem rust, using nine different specialized (biologic) forms of stem rust common to the spring-wheat area. In addition to the epidemic artificially produced at St. Paul, opportunity to study rust resistance of the material was afforded by the occurrence of natural infection at Mandan, N. Dak.

Important factors concerned with drought resistance were thought to be the presence or absence of awns, earliness of heading, height, and plant productiveness. The color of glumes and kernels apparently have no particular connection with resistance to rust or drought, but were included to complete the study of the principal contrasting parental characters in the cross. The kernel color is of great economic importance. Red-kerneled varieties are demanded in the northern Prairie and Great Plains areas, while white wheats are preferred in the Pacific Coast States.

The study here reported is concerned principally with the development of a hard red spring wheat for the northern Great Plains area. The principal experiments were conducted at the Northern Great Plains Field Station, Mandan, N. Dak., because there both rust and drought may occur with destructive severity. The cross, however, is being used for breeding a common white wheat resistant to rust and drought, for the Pacific Coast States, particularly California, where losses from black stem rust are not infrequent.

DESCRIPTION OF THE F_1

The F_1 plants bore apical awns, varying from 3 to 20 mm. in length. This was different from the Hard Federation parent, which is almost entirely awnless. The glumes of the F_1 plants were brown, but a somewhat lighter brown than those of the Hard Federation parent. The plants which were grown at Chico, Calif., showed a slight infection of both stem rust and leaf rust. They were tall but had the stiff stems of the Hard Federation parent. The kernels were not especially hard, being somewhat softer than those of either of the parents, and showed occasional indication of "yellowberry." Some of the kernels appeared to be much softer than others. The kernels were slightly longer than those of either of the parents. A spike of an F_1 plant is shown in Plate 1, A in comparison with spikes of the parents.

The F_1 plants grown at St. Paul, Minn., in 1922, proved to be susceptible to stem rust.

SEGREGATION OF CHARACTERS IN THE F_2 AND F_3

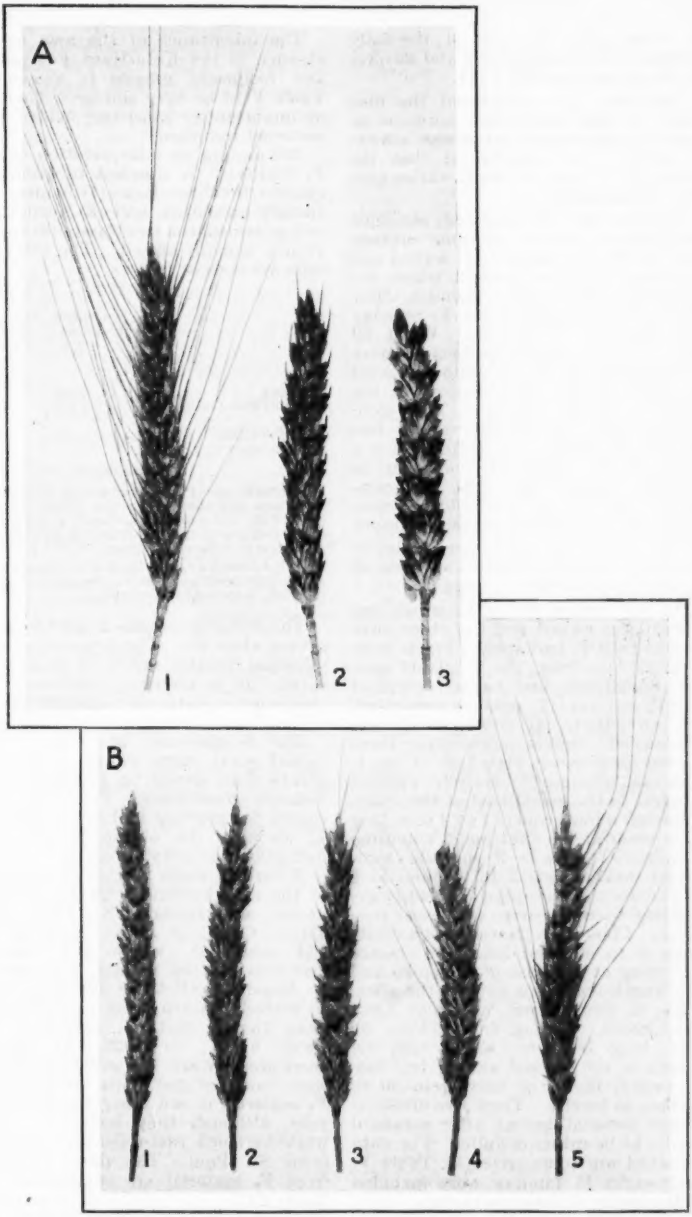
A study of individual plants for the characters previously mentioned was made on the F_2 material grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., except that yields of the individual plants were not obtained from the California material.

In the F_3 certain plant characters were further studied at Mandan, N. Dak., and Davis, Calif. Only at Mandan were yields of individual plants obtained. Notes on rust resistance were obtained at both St. Paul and Mandan.

A summary of the data recorded on the segregation of characters in F_2 and F_3 is presented.

AWNS AND THEIR ABSENCE

Biffen (*4*) stated that "the beardless condition is a dominant, the bearded a recessive character." Other early workers, particularly Tschermak (*35*) and Spillman (*32*), obtained similar results in the first generation and also showed that in the second generation the awnless and awned plants occur in the monohybrid Mendelian ratio of 3:1.



Inheritance in Kota—Hard Federation Crosses Plate I

A.—Typical spikes of the varieties used as parents in the cross studied, together with the first generation progeny. (1) Kota, (2) F_1 hybrid, and (3) Hard Federation
B.—Spikes of F_2 hybrids representing the 5 classes for expression of the awn character, namely, (1) awnless, (2) apically-awnletted, (3) awnletted, (4) short-awned, and (5) awned

In some cases the ratio of the fully awned to the intermediate and awnless in this generation was 1:2:1.

Saunders (*27*) questioned the idea that the first generation between an awnless and an awned wheat always is awnless and maintained that the character of awns in the F_1 varies with the wheats used.

Howard and Howard (*22*) obtained single-factor results in some crosses, but in others between fully awned and absolutely awnless parents, where the F_1 plants were nearly awnless, they were able to separate the F_2 progeny into five or six classes. When all the awned and awn-tipped classes were grouped as awned the ratio of awned to awnless was 15:1, indicating the presence of two factors. They concluded that for certain crosses two factors, B and T, must be present in a homozygous dominant condition in bearded wheats and that the completely awnless plants should be represented by the double recessive factors.

These researches and later studies by others have proved that awnlessness at least is only partially dominant.

In the present study, in which one parent was awned and the other awnless and the F_1 had apical awnlets from 3 to 20 mm. long, the F_2 plants were distributed into five classes, described as (1) awnless, (2) apically-awnletted, (3) awnletted, (4) short-awned, and (5) awned. Spikes representing these classes are shown in Plate 1, B. Class 1, awnless, normally is entirely without awnlets in the apical part of the spike, although a few awnlets 1 to 2 mm. long may occur at the apex under abnormal conditions. Class 2, apically-awnletted, has awnlets 2 to 20 mm. long at the apex of the spike but rarely extending to the central and basal portions. Class 3, awnletted, has awnlets from 3 to 40 mm. long, the shorter occurring at the base of the spike and the length increasing toward the apex. Class 4, short-awned, has short awns throughout, varying from 15 to 50 mm. long but only about half the length of the normal awns. In Class 5, awned, the awns vary from 30 to 80 mm. in length. These five divisions of the material appear, after a careful study, to be rather definite. The data obtained are summarized in Table V. Sixty-eight F_1 families were included in the study of these characters.

The inheritance of the awn or its absence in the Kota-Hard Federation and reciprocal crosses is shown in Table V to be very similar. There is no important or consistent evidence of maternal influence.

Attempting an interpretation of the F_2 results, it is simplest to group as awnless, the three classes (1) awnless, (2) apically-awnletted, and (3) awnletted; and as awned, the two classes (4) short-awned, and (5) awned. The total results are then as follows:

	Awnless, classes 1, 2, 3	Awned, classes 4, 5
Obtained	3,362	1,089
Expected on 3:1 ratio	3,338	1,113
Deviation	24	24
Probable error [a]		19.5

[a] Probable errors for numbers of individuals given here and elsewhere in this paper were obtained from tables of probable errors of Mendelian ratios, prepared in the Department of Plant Breeding, Cornell University, Ithaca, N. Y., from the formula $0.6744898\sqrt{npq}$ in which n is the total number of individuals and p and q the numbers corresponding to the ratios concerned.

The deviation of only 24 ± 19.5 shows a very close fit. The presence of one principal genetic factor is thus indicated. It is obvious, however, that this is not a certain or complete explanation.

The F_2 material, in general, contained many more awned or awnless plants than would be expected on a 2-factor hypothesis. Thus the necessity for growing and examining the F_3 progeny to obtain further information was very apparent.

A further study on the inheritance of the awn was made on F_3 material grown at Mandan, N. Dak., and Davis, Calif., in 1923. As many as 434 selections, which were mostly rust-resistant red wheats, were grown at Mandan. Of these 291 were from F_2 material grown there and 143 were from the F_2 material grown at St. Paul, Minn., in 1922. At Davis, there were grown 197 selections which were both red and white wheats from F_2 material grown there the previous year, although they included a few white-kerneled, rust-resistant selections from St. Paul. The data obtained from F_3 material are summarized in Table VI.

TABLE V.—*Segregation of 4,451 F_2 plants of Kota×Hard Federation and reciprocal crosses into five classes for awns or their absence, grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and cross	Number of F_1 families	Number and per cent of F_2 plants in classes					
		Awnless	Apically-awnletted	Awnletted	Short-awned	Awned	Total of all classes
DAVIS, CALIF.							
Kota×Hard Federation:							
Numbers	11	66	144	75	38	26	349
Percentages		18.9	41.3	21.5	10.9	7.4	100
Hard Federation×Kota:							
Numbers	19	78	287	154	113	46	678
Percentages		11.5	42.3	22.7	16.7	6.8	100
Total:							
Numbers	30	144	431	229	151	72	1,027
Percentages		14.0	42.0	22.3	14.7	7.0	100
ST. PAUL, MINN.							
Kota×Hard Federation:							
Numbers	20	49	201	233	79	94	656
Percentages		7.5	30.7	35.5	12.0	14.3	100
Hard Federation×Kota:							
Numbers	40	66	455	221	130	94	966
Percentages		6.8	47.1	22.9	13.5	9.7	100
Total:							
Numbers	60	115	656	454	209	188	1,622
Percentages		7.1	40.4	28.0	12.9	11.6	100
MANDAN, N. DAK.							
Kota×Hard Federation:							
Numbers	12	64	391	386	149	156	1,146
Percentages		5.6	34.1	33.7	13.0	13.6	100
Hard Federation×Kota:							
Numbers	15	59	295	138	71	93	656
Percentages		9.0	45.0	21.0	10.8	14.2	100
Total:							
Numbers	27	123	686	524	220	249	1,802
Percentages		6.8	38.1	29.1	12.2	13.8	100
Grand total:							
Numbers	68	382	1,773	1,207	580	509	4,451
Percentages		8.6	39.9	27.1	13.0	11.4	100

TABLE VI.—*Segregation of 16,144 F_3 plants of the Kota-Hard Federation and reciprocal crosses for awn classes at Mandan, N. Dak., and Davis, Calif., in 1923*

F_2 classes and breeding behavior in the F_3	Segregation of F_2 families and F_3 plants								
	Mandan, N. Dak.								
	F_2 families		Per cent of F_2[a]	Classes of F_3 plants					Total
	Number of plants	Per cent of class		1	2	3	4	5	
Awnless, 1:									
1	1	2.9	0.2	16					16
1 and 2	20	57.1	3.9	288	176				464
1 to 3	7	20.0	1.4	57	72	25			154
1 to 4	7	20.0	1.4	84	46	16	16		162
Class total	35	100.0	6.9	445	294	41	16		796
Apically-awnletted, 2:									
2	9	6.0	2.3		193				193
2 and 3	41	27.3	10.4		691	238			929
2 to 4	28	18.6	7.1		429	98	112		639
2 to 5	26	17.3	6.6		267	149	65	76	557
1 and 2	4	2.7	1.0	27	68				95
1 to 3	16	10.7	4.1	55	224	88			367
1 to 4	19	12.7	4.8	73	236	63	67		439
1 to 5	7	4.7	1.8	20	81	26	22	29	178
Class total	150	100.0	38.1	175	2,189	662	266	105	3,397
Awnletted, 3:									
3	9	8.1	2.4			224			224
3 to 5	19	17.1	5.0			352	81	31	464
2 to 5	64	57.7	16.7		427	881	211	150	1,669
1 to 5	12	10.8	3.1	25	84	126	45	27	307
1 to 4	6	5.4	1.6	14	35	81	17		147
1 to 3	1	.9	.3	4	16	8			28
Class total	111	100.0	29.1	43	562	1,672	354	208	2,839
Short-awned, 4:									
4	2	4.8	.6				43		43
4 to 5									
3 to 5	18	42.8	5.2			198	169	55	422
3 to 4	16	38.1	4.6			194	179		373
2 to 5	4	9.5	1.2		13	42	40	17	112
2 to 4	2	4.8	.6		17	22	6		45
Class total	42	100.0	12.2		30	456	437	72	995
Awned, 5:									
5	23	24.0	3.3					560	560
4 and 5	18	18.7	2.6				92	336	428
3 to 5	52	54.2	7.5			160	294	801	1,255
2 to 5	3	3.1	.4		13	26	7	24	70
Class total	96	100.0	13.8		13	186	393	1,721	2,313
Grand total	434	500.0	100.1	663	3,088	3,017	1,466	2,106	10,340

TABLE VI.—*Segregation of 16,144 F_3 plants of the Kota-Hard Federation and reciprocal crosses for awn classes at Mandan, N. Dak., and Davis, Calif., in 1923*—Continued

F_2 classes and breeding behavior in the F_3	Segregation of F_2 families and F_3 plants—Continued								
	Davis, Calif.								
	F_2 families		Per cent of F_2[a]	Classes of F_3 plants					Total
	Number of plants	Per cent of class		1	2	3	4	5	
Awnless, 1:									
1	15	29.4	4.1	392					392
1 and 2	12	23.5	3.3	227	116				343
1 to 3	21	41.2	5.8	324	215	88			627
1 to 4	3	5.9	.8	36	19	19	8		82
Class total	51	100.0	14.0	979	350	107	8		1,444
Apically-awnletted, 2:									
2	1	2.0	.8		31				31
2 and 3	6	12.0	5.0		139	57			196
2 to 4	4	8.0	3.4		51	48	23		122
2 to 5	2	4.0	1.7		32	19	7	12	70
1 and 2	4	8.0	3.4	69	58				127
1 to 3	14	28.0	11.8	126	275	87			488
1 to 4	5	10.0	4.2	46	93	30	19		188
1 to 5	14	28.0	11.8	58	190	100	54	44	446
Class total	50	100.0	42.1	299	869	341	103	56	1,668
Awnletted, 3:									
3									
3 to 5									
2 to 5	7	53.8	12.0		80	80	49	33	242
1 to 5	4	30.8	6.9	26	65	31	20	13	155
1 to 4	1	7.7	1.7	3	15	8	3		29
1 to 3	1	7.7	1.7	6	26	6			38
Class total	13	100.0	22.3	35	186	125	72	46	464
Short-awned, 4:									
4									
4 to 5	1	5.3	.8				6	3	9
3 to 5	9	47.3	7.0			49	104	66	219
3 to 4	1	5.3	.8			12	13		25
2 to 5	7	36.8	5.4		18	64	85	35	202
2 to 4	1	5.3	.8		15	31	3		49
Class total	19	100.0	14.8		33	156	211	104	504
Awned, 5:									
5	49	76.6	5.4					1,296	1,296
4 and 5	4	6.2	.4				15	114	129
3 to 5	6	9.4	.7			30	50	68	148
2 to 5	5	7.8	.5		14	29	57	51	151
Class total	64	100.0	7.0		14	59	122	1,529	1,724
Grand total	197	500.0	100.2	1,313	1,452	788	516	1,735	5,804

[a] Weighted in proportion to percentage of F_2 plants in each class of total for same station in 1922 given in Table V.

The F_1, which was apically-awnletted, approached more closely to the awnless than the awned parent. If the data can be interpreted on a 1-factor basis it is necessary to look for the 25 per cent of recessives among those having more awn development than F_1. In F_2, classes 4 and 5 combined include 26 per cent at Mandan, 24.5 per cent at St. Paul, and 21.7 per cent at Davis. The total number of plants, constituting 24.4 per cent, was shown to be not significantly different from the 3:1 ratio and suggests that the awned and short-awned classes represent the recessive type.

In F_3, however, the awned or short-awned classes did not breed true within the limits of classes 4 and 5 combined, either at Mandan or at Davis. At both points only about 6.5 per cent of the whole F_2 bred true to these limits. Thus the simple hypothesis that classes 4 and 5 are due to a single recessive factor is untenable.

It may be assumed that those plants recessive with respect to the primary factor, if any, are distributed among classes 3, 4, and 5. As these classes make up 55.1 per cent of the F_2 population at Mandan and 44 per cent of that at Davis, it is necessary to assume that a large part of classes 3, 4, and perhaps even 5 (which does not wholly breed true within the limits of classes 3 to 5) exceed the F_1 in amount of awn because of some other factor than the one being considered as primary. Only a part of these classes (3, 4, 5) breed true to their wide range. At Mandan, 31.2 per cent of the F_2 was composed of such plants (classes 3, 4, and 5 producing only 3, 4, and 5) but only 15.1 per cent at Davis. Evidently it is possible to find a recessive class in the Mandan group data, but the Davis group data indicate that some of these classes recessive in the most inportant factor must have been as low as class 2. It is very clear that there is no one outstanding recessive factor responsible for the awned condition.

Looking at the other end of the F_2 series for the homozygous dominant class, it is shown in Tables V and VI that while 44.9 per cent at Mandan and 56 per cent at Davis were of classes 1 and 2, there were only 7.4 per cent at Mandan, and 11.6 per cent at Davis, of classes 1 and 2 of the F_2 population which produced only classes 1 and 2. Thus with reference to the most important factor homozygotes must be looked for in class 3 as well as in classes 1 and 2. Twenty-six per cent of the F_2 generation at Mandan and 35.9 per cent at Davis, were of classes 1, 2, and 3 producing only 1, 2, and 3. These can include all homozygous dominants. Thus it is possible that there may be a dominant factor present in classes 1 to 3 and a recessive factor present in classes from 3 to 5 at Mandan and in classes 2 to 5 at Davis, with heterozygotes appearing in classes from 1 to 4 and perhaps even 5.

To account for this wide range and necessary overlap of the classes containing the homozygous dominant or recessive for the most important factor, it is necessary to assume the existence of a second factor, or a group of factors, nearly if not fully as important as the first.

On the hypothesis that there are two factors of equal importance, it will be necessary to find 6.25 per cent of the F_2 strains at each extreme breeding true. Only 3. 3 per cent of the Mandan F_2 were of class 5 breeding true to 5, and 5.4 per cent of the Davis F_2 were of that sort. It thus is necessary to suppose that some of the 2-factor recessives were in class 4. At the other extreme only 0.2 per cent of the Mandan F_2 were of class 1 breeding true to 1, and 4.1 per cent of the Davis F_2 were of that sort. Thus some 2-factor homozygous dominants must be looked for in class 2. There were 6.4 per cent of F_2 classes 1 and 2 which produced only 1 and 2 at Mandan, and 11.6 per cent in the Davis F_2. At the other extreme there were 6.5 per cent of Mandan F_2 and 6.6 per cent of Davis F_2 of classes 4 and 5 producing only 4 and 5. The 2-factor homozygous dominant and recessive (expectation 6.25 per cent) thus can be found in classes 1 to 2 and 4 to 5, respectively, but additional factors are necessary to account for the variation remaining.

To have arbitrarily assumed the awnless to be the recessive class, as Howard and Howard (*22*) had done in their 2-factor hypothesis and then grouped the remaining classes as awned, 6.25 per cent of the awnless plants should have bred true. As only 0.2 per cent of class 1 bred true for class 1 at Mandan, and 4.1 per cent at Davis, it is apparent that their findings could not apply to this cross. The writer, therefore, assumes that, for the Kota-Hard Federation and reciprocal crosses here studied, two factors at least must be present in a dominant condition in awnless strains, and that the awned plants should be represented at least by double recessive factors. This is a conclusion opposite to that of Howard and Howard.

The 2-factor hypothesis here advanced does not entirely explain the

inheritance of awns in this cross. Complete homozygosity for awned or awnless strains apparently is due to multiple factors.

EFFECT OF AWNS ON YIELD.—The physiological effect of the awn on yield is a point of considerable economic importance. Grantham (*17*) found that awned wheats outyielded awnless on the average of many varieties. Hayes (*19*) has summarized the important papers on this subject, and after a study of awnless, tip-awned, and bearded strains from Marquis-Preston crosses states:

> The awn of wheat is, therefore, an important organ, and the present tendency to breed only awnless wheat should not be adopted in entirety without further experimental studies.

Most of the physiological studies have been with barley, the most recent being that of Harlan and Anthony (*18*) who found that the elimination of the awns resulted not only in lower yields, but in increased tendency toward shattering as well. Perlitius (*26*) worked with wheat as well as barley. He made transpiration studies with both winter and spring wheats, using (1) awned, (2) awns removed, and (3) awnless lots. He concluded:

> The awns of the spike are important for transpiration. This transpiration is nearly half that of the total transpiration of the head when awned heads of wheat and heads with awns removed are compared.

He also stated:

> The awn has an important influence on the volume and weight of the kernel [and] a marked effect on kernel quality which exhibited itself chiefly in an increase in starch content in awned sorts.

Schmid (*28*) had previously shown, after careful experiments, that awnless varieties have higher gluten content than awned. He also stated that—

> the physiological service of the awn supplies a not unimportant work for the normal building of the fruit. The amount of its importance stands in direct relation to the size of the awn.

In the present study the mean yields of F_2 plants of each awn class and their probable errors have been obtained from two sources. The data are given in Table VII.

The F_2 data, especially those from Mandan, N. Dak., show that there is a direct relation between the awn length and the yield. The data from St. Paul are not as consistent as those from Mandan, although the difference between the extreme and the parent classes is greater. The difference between the awnless and awned classes at St. Paul is 15 per cent, or 0.56 ± 0.23 grams. This difference is 2.43 times its probable error and represents odds of about 9:1. At Mandan the difference between the same classes is 11 per cent or 0.44 ± 0.18 grams. This difference is 2.44 times its probable error, also indicating odds of about 9:1. While these differences can not be definitely said to be significant, the awns apparently are of some importance under droughty as well as humid conditions.

In 1923 nine hundred F_3 plants grown at Mandan, N. Dak., were threshed and the yields of the five awn classes averaged. These data are given in Table VIII.

TABLE VII.—*Mean yield and its probable error of five awn classes of F_2 plants of Kota-Hard Federation crosses grown at St. Paul, Minn., and Mandan, N. Dak. in 1922*

Locality and class	Number of plants	Yield in grams, mean and probable error
ST. PAUL, MINN.		
Awnless	45	3.70±0.17
Apically-awnletted	171	3.67± .11
Awnletted	200	4.15± .12
Short-awned	68	3.85± .18
Awned	78	4.26± .15
Total and average	562	3.95± .06
MANDAN, N. DAK.		
Awnless	63	3.91± .15
Apically-awnletted	389	4.11± .08
Awnletted	387	4.13± .06
Short-awned	148	4.16± .09
Awned	156	4.35± .10
Total and average	1,143	4.06± .03

TABLE VIII.—*Mean yield and its probable error for five awn classes of F_3 plants of Kota-Hard Federation crosses grown at Mandan, N. Dak., in 1923*

Class	Number of plants	Yield in grams, mean and probable error
Awnless	126	2.79±0.06
Apically-awnletted	403	3.02± .04
Awnletted	111	3.02± .07
Short-awned	73	3.06± .08
Awned	187	3.30± .06
Total and average	900	3.05± .03

These further data show a similar definite relationship between the awn length and yield. The difference between the extreme classes in this latter case is 18 per cent or 0.51 ± 0.08 gram. As this difference is over six times its probable error it certainly may be considered significant. Many factors are associated with the complex character designated yield, and it appears that the factors for the development of awns are among those involved.

COLOR OF THE GLUMES

Glume colors are variously classed as white, yellowish, brown or red. Two classes usually are used, namely, white and brown. Those classed as white may vary from nearly white to yellowish and those classed as brown may show various shades of brown to a brownish red. Biffen (*4*) found brown glume color dominant to white in the single 3 to 1 ratio. No other ratio is known to have been reported by other workers in crosses between common wheats.

The present study includes F_2 data on the segregation for color of the glumes at the three points, Davis, Calif., St. Paul, Minn., and Mandan, N. Dak. The results obtained are given in Table IX.

TABLE IX.—*Segregation of 4,442 F_2 plants of the Kota-Hard Federation and reciprocal crosses into two classes for color of glumes, when grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and cross	Number of F_1 families	Number and percentage of F_2 plants having—				Total number	Deviation from 3:1 ratio	Probable error
		Brown glumes		White glumes				
		Number	Per cent	Number	Per cent			
DAVIS, CALIF.								
Kota×Hard Federation	11	245	70.0	105	30.0	350	18	5.46
Hard Federation×Kota	19	490	72.1	190	27.9	680	20	7.62
Total	30	735	71.4	295	28.6	1,030	38	9.38
ST. PAUL, MINN.								
Kota×Hard Federation	20	376	57.7	276	42.3	652	113	7.46
Hard Federation×Kota	40	665	69.3	294	30.7	959	54	9.04
Total	60	1,041	64.6	570	35.4	1,611	167	11.73
MANDAN, N. DAK.								
Kota×Hard Federation	12	789	68.9	356	31.1	1,145	70	9.88
Hard Federation×Kota	15	502	76.5	154	23.5	656	10	7.48
Total	27	1,291	71.7	510	28.3	1,801	60	12.40
ALL THREE STATIONS								
Kota×Hard Federation	23	1,410	65.7	737	34.3	2,147	200	13.54
Hard Federation×Kota	45	1,657	72.2	638	27.8	2,295	64	13.99
Grand total	68	3,067	69.0	1,375	31.0	4,442	264	19.48

With this character there is evidence of slight maternal influence on the reciprocal crosses as there is a consistant difference in the percentage at all three points. The percentages of white-glumed plants are the greater when Kota is used as the female parent and the percentages of brown-glumed plants are greater with Hard Federation as the female parent.

The totals of white-glumed plants in the reciprocal crosses at each of the three stations in the grand total show that there resulted a considerably larger number of plants having white glumes than would be expected on a 3:1 basis in general, the ratio being nearer 2:1 than 3:1. A close fit to the expected 3:1 ratio was obtained for the Hard Federation × Kota cross at Davis and Mandan, where the deviations were 20 ± 7.62 and 10 ± 7.48, respectively. At St. Paul, the results from this cross also were much nearer a good fit than the reciprocal, although significantly different from the expected ratio, which is true also for the total. It is important, however, that where Hard Federation, which has brown glumes and the dominant color, was used as the female parent, a close fit was obtained under two of the three different sets of conditions.

It will be recalled that brown glumes in the F_1 were a somewhat lighter brown than that of Hard Federation. Considerable variation was apparent in the F_2 regarding glumes classed as brown or white. The glumes of Kota are yellowish rather than white, but there appeared to be some white-glumed plants in the F_2 progeny. The differences, however, were not contrasting enough to permit any more definite grouping, even with the material from Davis, Calif., where growing conditions were ideal and the colors almost perfectly developed. At Mandan and more particularly at St. Paul, summer rains and damage by rust made separations on the two colors difficult. The study was continued in the F_3 at Mandan and Davis and the data obtained are given in Table X.

TABLE X.—*Segregation of 15,946 F_3 plants of the Kota-Hard Federation and reciprocal crosses into two classes for color of glumes, when grown at Mandan, N. Dak., and Davis, Calif., in 1923*

Source, F_2 classes, and segregation in the F_3	F_2 families		F_3 plants		
	Number	Percentage of class	Percentage of F_2[a]	Glumes	
				Brown	White
MANDAN, N. DAK.					
Glumes white:					
White	126	81.8	23.1	----------	2,918
White and brown	28	18.2	5.2	280	360
Total	154	100.0	28.3	280	3,278
Glumes brown:					
Brown	72	25.8	18.5	1,704	----------
Brown and white	207	74.2	53.2	3,300	1,657
Total	279	100.0	71.7	5,004	1,657
Mandan total	433	200.0	100.0	5,284	4,935
DAVIS, CALIF.					
Glumes white:					
White	75	89.3	25.5	----------	2,118
White and brown	9	10.7	3.1	156	57
Total	84	100.0	28.6	156	2,175
Glumes brown:					
Brown	45	39.8	28.4	1,350	----------
Brown and white	68	60.2	43.0	1,488	558
Total	113	100.0	71.4	2,838	558
Davis total	197	200.0	100.0	2,994	2,733

[a] Weighted in proportion to percentage of F_2 plants in each class of total for same station in 1922, given in Table IX.

The F_3 results show that some of the plants classed as white segregated for white and brown. The percentages of these were larger at Mandan than at Davis. Correcting the F_2 Davis results on the basis of the F_3 plants grown at that station, the following results are obtained:

	Brown	White
Obtained (uncorrected)	735	295
Corrected on basis of F_3	767	263
Expected on 3:1 ratio	772	258
Deviation	5	5
Probable error	9.38	

The deviation of 5 ± 9.38 shows a very close fit.

A similar correction of the Mandan F_2 results on the basis of the F_3 plants grown there gives the following:

	Brown	White
Obtained (uncorrected)	1,291	510
Corrected on basis of F_3	1,384	417
Expected on 3:1 ratio	1,351	450
Deviation	33	33
Probable error	12.4	

This deviation of 33 ± 12.4 is not significantly different from the expected ratio as it is less than three times the probable error.

At St. Paul the F_2 plants were shown to have a greater percentage of white glumed plants than occurred at either Davis or Mandan. The Kota-Hard Federation cross particularly segregated in that manner, due possibly to maternal influence, although the environmental conditions at St. Paul were less favorable than at the other points for developing and maintaining natural glume colors. It is quite probable, therefore, that there was a greater error in the classification of the St. Paul material, which, together with the possible maternal influence, may account for the differences.

Of the 28 F_2 white-glumed families at Mandan which segregated for white and brown glumes, 19 produced more white-glumed plants than brown. The average for the 28 families was 13 white to 10 brown. There were also 7 additional families included among the true-breeding white which produced 1 to 4 questionable brown-glumed plants. The occurrence of these questionable plants or of more white-glumed plants than brown can not be satisfactorily explained and may be due to natural crossing. At Davis the 9 families classed as white-glumed in F_2 and which broke up into brown-glumed and white-glumed in F_3 segregated in the expected 3:1 ratio, the deviation being 4 ± 4.26. There were no families which had more white-glumed plants than brown, although one family had an equal number of each.

The number of F_2 families of the brown-glumed class at Mandan separated into homozygous and heterozygous families in the F_3 closer to a 1:3 ratio than to the expected 1:2. At Davis, however, a close agreement to the 1:2 ratio was obtained, the deviation being 7 ± 3.24, which is not significantly different from the expected.

Of the heterozygous brown-glumed F_2 families at Mandan the F_3 plants segregated in a ratio very close to 1:2 rather than 1:3. This is very similar to the F_2 results and is what would be expected to reoccur. At Davis, although the ratio is nearer the 1:3, the deviation is 46 ± 13.24, which also is significantly different.

In spite of the several unexpected segregations and ratios obtained in both F_2 and F_3 there is no reliable evidence of more than a single genetic factor involved in the color of glumes in this cross. The frequent lack of a significant fit to the 3:1 ratio apparently is due to environment, but may be due to natural crossing and possibly maternal influence.

COLOR OF THE KERNEL

The inheritance of kernel color has been explained by one, two, and three Mendelian factors. Biffen (*4*) found that red was dominant to white in F_1 and segregated in a 3:1 ratio in F_2. Nilsson-Ehle (*24*) was the first to report crosses which in F_2 gave 15:1 and 63:1 ratios of red-kerneled and white-kerneled plants, proving the presence of two and three factors. Howard and Howard (*22*) of India, and Gaines (*15*) in Washington have since obtained similar ratios.

In the cross here reported red proved dominant as usual in F_1, and the data on segregation in F_2 are given in Table XI.

TABLE XI.—*Segregation of 4,432 F_2 plants of the Kota-Hard Federation and reciprocal crosses into two classes for color of kernels, when grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and cross	Number of F_1 plants	Number and percentage of F_2 plants					Deviation from 15:1	Probable error
		Red kernels		White kernels		Total number		
DAVIS, CALIF.			*Per cent*		*Per cent*			
Kota×Hard Federation	11	325	92.9	25	7.1	350	3	3.05
Hard Federation×Kota	19	643	94.6	37	5.4	680	5	4.26
Total	30	968	94.0	62	6.0	1,030	2	5.24
ST. PAUL, MINN.								
Kota×Hard Federation	20	615	94.3	37	5.7	652	4	4.17
Hard Federation×Kota	40	922	96.1	37	3.9	959	23	5.06
Total	60	1,537	95.4	74	4.6	1,611	27	6.52
MANDAN, N. DAK.								
Kota×Hard Federation	12	1,085	94.9	58	5.1	1,143	13	5.53
Hard Federation×Kota	15	626	96.6	22	3.4	648	19	4.16
Total	27	1,711	95.5	80	4.5	1,791	32	6.88
ALL THREE STATIONS								
Kota×Hard Federation	23	2,025	94.4	120	5.6	2,145	14	7.59
Hard Federation×Kota	45	2,191	95.8	96	4.2	2,287	47	7.79
Grand total	68	4,216	95.1	216	4.9	4,432	61	10.86

The data in Table XI show a fairly good agreement to a 2-factor or 15:1 ratio. For this ratio 93.75 per cent should be red-kerneled and 6.25 per cent white. The grand total shows 95.1 per cent red and 4.9 per cent white or a deviation from the 15:1 ratio of 59 ± 10.86, and, therefore, is not a close fit. A more detailed study of the data shows that in some cases there were no significant differences.

There again is evidence of slight maternal influence on this character in the reciprocal crosses, as there is a consistant difference in the percentages at all three points. The numbers and percentages for the Kota×Hard Federation cross show a close fit to the two-factor hypothesis at each of the three localities and in the total for all. The reciprocal cross, however, in which Hard Federation is the female parent and which has the white or recessive type of kernel, shows a close fit at only one of the three localities, Davis, Calif., and not in the total for all.

A more certain separation of the kernels into the red and white classes was possible with the Davis, Calif., material than with that from St. Paul, Minn., and Mandan, N. Dak. Environmental conditions could account for the close fit which was obtained from the total material grown at Davis and for the significantly different results for the total material at St. Paul and Mandan.

It would appear therefore that two Mendelian factors are involved in kernel color in this cross, and that the lack of a significantly close fit to the 15:1 ratio in the reciprocal or Hard Federation×Kota cross and in the grand total is due to environmental conditions and possible slight maternal influence. When Kota, which has the dominant red kernels, was used as the female parent, a significantly close fit was obtained under all three different conditions.

In order further to determine the factors involved, F_3 material of the 1923 crop from Davis, Calif., was studied. The data obtained are given in Table XII.

TABLE XII.—*Segregation of 5,737 F_3 plants of the Kota-Hard Federation and reciprocal cross into two classes for color of kernel, when grown at Davis, Calif., in 1923*

F_2 classes and segregation in the F_3	Davis, Calif.						
	F_2 families		F_3 plants				
	Numbers	Percentage of class	Percentage of F_2	Kernels		Deviation from ratio indicated	Probable error
				Red	White		
Kernels white:							
White	80	100.0	6.0	----------	2,495	----------	----------
Total	80	100.0	6.0	----------	2,495	----------	----------
Kernels red:							
Red	55	47.0	44.2	1,501	----------	----------	----------
Red and white—							
3:1 ratio	37	31.6	29.7	821	254	15	9.59
15:1 ratio	25	21.4	20.1	623	43	1	4.21
Total	117	100.0	94.0	2,945	297	----------	----------
Grand total	197	200.0	100.0	2,945	2,792	----------	----------

The data show that the white-kerneled strains bred true to that color. The red-kerneled strains bred true or segregated into red and white in either the 3:1 or 15:1 ratios. From the 37 F_2 families which segregated according to the 3:1 ratio there were 821 red-kerneled plants to 254 white in F_3, a deviation from the expected of 15 ± 9.59. Of the 666 F_3 plants which segregated according to the 15:1 ratio the deviation from expected was 1 ± 4.02, which indicates an unusually close fit.

Of the F_2 red-kerneled strains, seven-fifteenths, or 46.7 per cent, should have bred true and four-fifteenths, or 26.7 per cent, should have segregated in both the 3:1 and the 15:1 ratios. As shown in Table XII, the percentages obtained were very close to the expected.

DATE OF HEADING

Earliness often is an important economic factor in successful spring-wheat production in the dry sections of the United States. The date of heading is thought by the writer to be the best note to use in a study of earliness under drought and rust conditions. It is more reliable and shows a greater range of variation than the date of ripening where adverse environmental conditions affect the wheat crop near maturity.

Farrer (*11*) found earliness in wheat hybrids to be intermediate between the parents and that there was no difference in the reciprocal of a cross. Biffen (*4*) in an interspecific cross between Polish, an early wheat, and Rivet, a late wheat, concluded that earliness was dominant. Freeman (*14*), in a cross between durum and common wheat, found in F_2 and F_3 that the average date of heading, while intermediate, was nearer that of the late parent, indicating that lateness is at least partially dominant. Thompson (*34*) made numerous crosses between eight varieties of wheat ranging from very early to late. In the F_1 nearly all crosses ripened near the mean of the later parent. In the F_2 the great majority of plants were intermediate between the parents, indicating blending. The apparent dominance of lateness in F_1 could be explained only as due to heterosis or hybrid vigor. The further results of individual crosses were explained on the "multiple determiner hypothesis of blending." Bryan and Pressley (*5*), in a cross between Sonora and Turkey, found the F_1 intermediate in time of heading between the parents and the F_2 majority inclined toward the late parent. Florell (*13*) in a Sunset-Marquis cross concluded earliness to be dominant from F_2 "in the proportion of 3.11 to 0.89, indicating one allelomorphic pair of factors, with possibly a number of minor modifying factors."

TABLE XIII.—*Segregation of 2,487 F_2 plants of the Kota-Hard Federation or reciprocal crosses, in comparison with parents, into two-day classes for date of heading, when grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and class by dates of heading	Number and percentage of plants on date of heading							
	F_2 plants				Hard Federation		Kota	
	Kota × Hard Fed.	Hard Fed. × Kota	Total	Percentage	Number	Percentage	Number	Percentage
DAVIS, CALIF.								
Apr. 20					1	2.5		
22		4	4	0.5	8	20.0		
24	5	10	15	1.7	15	37.5		
26	23	48	71	8.1	13	32.5		
28	62	169	231	26.3	2	5.0		
30	113	216	329	37.5	1	2.5		
May 2	56	75	131	14.9				
4	31	45	76	8.7				
6	8	10	18	2.1			2	5.1
8	1	2	3	.3			21	53.8
10							12	30.8
12							2	5.1
14							2	5.1
Total	299	579	878	100.1	40	100.0	39	99.9
ST. PAUL, MINN.								
June 18	286			52.9	15	48.4		
20	109			20.3	9	29.0	4	11.4
22	70			12.9	4	12.9	15	42.8
24	34			6.3			12	34.3
26	30			5.5	3	9.7	3	8.6
28	12			2.2			1	2.9
Total	541			100.1	31	100.0	35	100.0
MANDAN, N. DAK.								
June 26	4			.4				
28	205			19.2	3	4.4		
30	253			23.7	28	41.2		
July 2	154			14.4	19	27.9		
4	197			18.4	8	11.8	1	1.2
6	154			14.4	9	13.2	32	39.0
8	65			6.1	1	1.5	28	34.1
10	24			2.3			17	20.7
12	7			.7			3	3.7
14	5			.5			1	1.2
Total	1,068			100.1	68	100.0	82	99.9

TABLE XIV.—*Average date of heading of F_2 hybrids and of the parents, Kota and Hard Federation, grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Station	F_2 hybrid		Kota		Hard Federation	
	Number of plants	Date	Number of plants	Date	Number of plants	Date
Davis, Calif.	828	Apr. 30	39	May 9	40	Apr. 24
St. Paul, Minn.	541	June 20	35	June 22	31	June 19
Mandan, N. Dak.	1,068	July 2	82	July 10	68	July 2

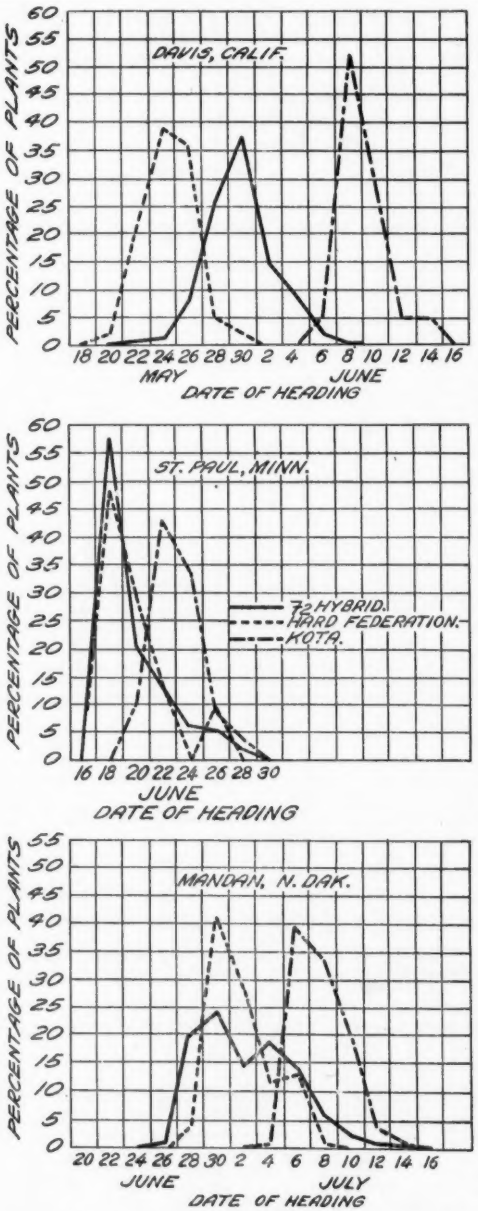

DAVIS, CALIF.
PERCENTAGE OF PLANTS
60 55 50 45 40 35 30 25 20 15 10 5 0
18 20 22 24 26 28 30 2 4 6 8 10 12 14 16
MAY
JUNE
DATE OF HEADING
ST. PAUL, MINN.
PERCENTAGE OF PLANTS
60 55 50 45 40 35 30 25 20 15 10 5 0
F2 HYBRID.
HARD FEDERATION.
KOTA.
16 18 20 22 24 26 28 30
JUNE
DATE OF HEADING
MANDAN, N. DAK.
PERCENTAGE OF PLANTS
55 50 45 40 35 30 25 20 15 10 5 0
20 22 24 26 28 30 2 4 6 8 10 12 14 16
JUNE
JULY
DATE OF HEADING

FIG. 1.—Frequency distribution, by dates of heading, of F_2 hybrids and of the Kota and Hard Federation parents at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922

In the present study comparisons of F_1 with parents are not available, but F_2 data compared with those from parent plants are available from three sources. Only at Davis, Calif., were reciprocal crosses studied for this character. The frequency distribution obtained is given in Table XIII and shown graphically in Figure 1. In the background of Plate 2 are shown the labeled plants growing at Davis, Calif. The dates of heading were obtained by tagging the plants individually on the day the first head emerged from the sheath. The average dates of heading for the F_2 hybrids and for the parents are given in Table XIV.

At Davis, Calif., the crop was fall sown and during the ideal spring conditions the dates of heading of the parents extended over a period of 26 days. The F_2 hybrids headed there during 18 of these days, as shown in Table XIII and in the upper portion of Figure 1. Earliness in the F_2 progeny appears partially dominant as the mode is nearer that of the early parent than of the late one. The reciprocal crosses at Davis show slight maternal influence. The mean dates together with their probable errors are as follows:

Kota × Hard Federation, April	29.65 ± .10
Hard Federation × Kota, April	29.13 ± .07
Difference	.52 ± .12

This difference of 0.52 ± 0.12 days, while small, is significant as it is 4.3 times its probable error, with odds of 267: 1 against the occurrence of such a difference being due to chance alone. With earliness dominant and present in the female parent, the slight maternal influence is exerted in the same manner as in the case of color of glumes and color of kernel.

Measuring the height of plant of F_2 hybrids of the Kota-Hard Federation cross at Davis, Calif., in 1922

Inheritance in Kota—Hard Federation Crosses

Plate 2

Measuring the height of plant of F_2 hybrids of the Kota-Hard Federation cross at Davis, Calif., in 1922

Further evidence that earliness is the dominant condition in this cross is shown by the results from St. Paul and Mandan in Table XIII and the central and lower portions, respectively, of Figure 1. At these points the material was spring sown and the heading period was shorter. At St. Paul heading started suddenly and the data obtained do not show normal variability. However, earliness appears dominant. At Mandan excellent data were obtained, which show the F_2 progeny to be much more variable than either of the parents and the mode and the mean to be the same as that of the early Hard Federation parent. The bimodal curve for the F_2 progeny and Hard Federation at Mandan was due principally to a rain which occurred on the 2d of July. It does not seem desirable to attempt a factor interpretation.

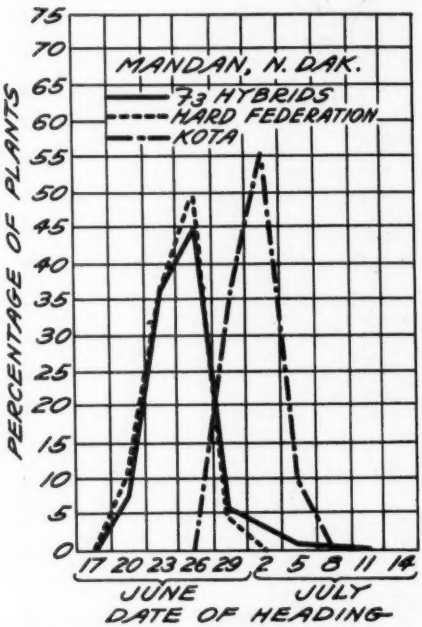


FIG. 2.—Frequency distribution, by dates of heading, of F_3 selections and of the Kota and Hard Federation parents at Mandan, N. Dak., in 1923

In 1923 at Mandan, N. Dak., 721 F_3 plants selected from among the 433 F_2 families grown there, were labeled for date of heading. At least one plant was labeled in each family and for the awnless, apically-awnletted and awned strains several plants were labeled in the most promising strains. The plant labeled usually was the earliest to head. Very few strains appeared as uniform in date of heading as the parents. The data thus obtained in F_3 in comparison with the parents are shown in Table XV and graphically in Figure 2.

The average date of heading for the F_3 selections was June 25, that of Hard Federation June 24, and that of Kota July 2. As earliness was one of the principal characters for which selections were made it is apparent that the desired earliness is being obtained.

TABLE XV.—*Date of heading of 721 F_3 plants of the Kota-Hard Federation cross, in comparison with the parents, grown at Mandan, N. Dak., in 1923*

Frequency classes	F_3 hybrid		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
June 20	58	8.0	11	11.6		
23	265	36.8	33	34.7		
26	324	44.9	47	49.5		
29	41	5.7	4	4.2	26	34.7
July 2	25	3.5			42	56.0
5	6	0.8			7	9.3
8	2	0.3				
	721	100.0	95	100.0	75	100.0

HEIGHT OF PLANT

Another growth character, height of plant, is an important economic factor in wheat production, because it may determine the method or ease of harvesting. It is inherited in the same manner as other characters.

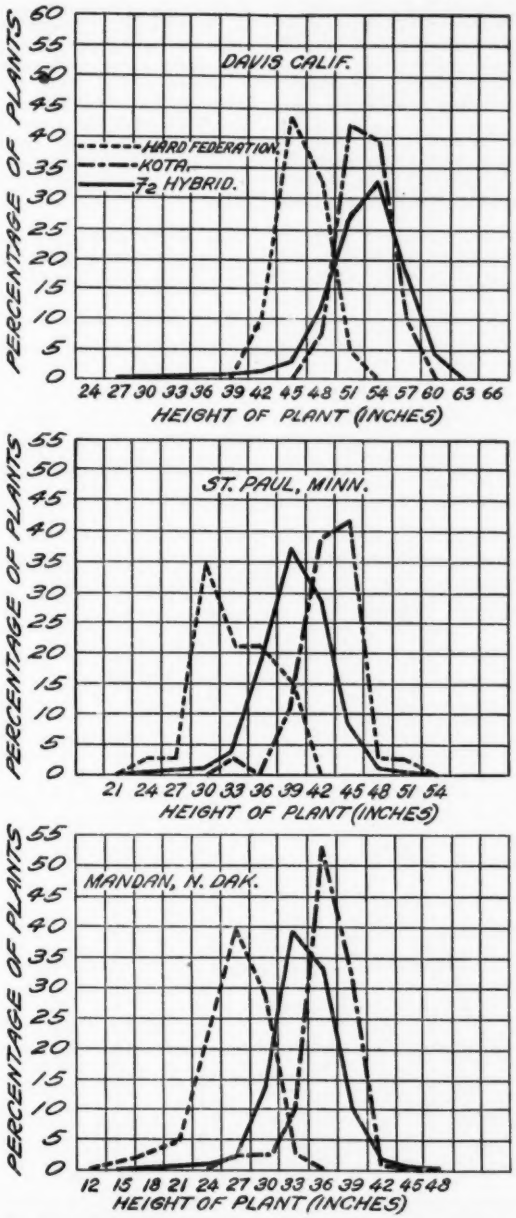


FIG. 3.—Frequency distribution, by height of plant, of F_2 hybrids and of the Kota and Hard Federation parents at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922

Freeman (*14*), in a durum-common wheat cross, found the F_1 hybrids taller than the tallest parent and a wide segregation for height in the F_2. There was greater variability in the shorter progenies, indicating a complex character.

In the present study, the height of the individual F_2 plants was measured at harvest time at the three stations where the material was grown. Plate 2 shows the writer taking height notes at Davis, Calif. Height was measured from the base of the culms to the tip of the spike, not including the awns of awned strains. The frequency distribution by height classes, comparing F_2 plants with the parents, is shown in Table XVI and graphically in Figure 3. Only at Davis, Calif., were reciprocal crosses studied for this character.

TABLE XVI.—*Segregation of 2,532 F_2 plants of the Kota-Hard Federation or reciprocal crosses, in comparison with parents, into 3-inch classes for height of plant, when grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and height classes (inches)	Number and percentage of plants on height of plant							
	F_2 hybrids				Hard Federation		Kota	
	Kota × Hard Federation	Hard Federation × Kota	Total	Percentage	Number	Percentage	Number	Percentage
DAVIS, CALIF.								
30		1	1	0.1				
33		2	2	.2	1	2.6		
36	1	3	4	.4	1	2.6		
39	4	3	7	.8	1	2.6		
42	4	7	11	1.2	4	10.2		
45	14	22	36	4.0	17	43.6		
48	49	70	119	13.3	13	33.3	3	7.5
51	85	145	230	25.6	2	5.1	17	42.5
54	100	197	297	33.1			16	40.0
57	54	99	153	17.0			4	10.0
60	12	24	36	4.0				
63	1	1	2	0.2				
Total	324	574	898	99.9	39	100.0	40	100.0
ST. PAUL, MINN.								
24	1			.2	1	3.1		
27	5			.9	1	3.1		
30	8			1.4	11	34.4		
33	22			3.9	7	21.9	1	2.8
36	101			17.8	7	21.9		
39	211			37.3	5	15.6	4	11.1
42	163			28.8			14	38.8
45	46			8.1			15	41.7
48	7			1.2			1	2.8
51	2			.4			1	2.8
Total	566			100.0	32	100.0	36	100.0
MANDAN, N. DAK.								
15					1	1.5		
18	1			.1	2	2.9		
21	3			.3	3	4.4		
24	5			.5	14	20.6		
27	24			2.2	27	39.7	2	2.4
30	145			13.6	19	28.0	2	2.4
33	416			38.9	2	2.9	7	8.5
36	351			32.8			44	53.7
39	101			9.5			26	31.7
42	21			2.0			1	1.2
45	1			.1				
Total	1,068			100.0	68	100.0	82	99.9

TABLE XVII.—*Mean height, standard deviation, and coefficient of variation for height of plant of F_2 hybrids and for the Kota and Hard Federation varieties, grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922*

Station and material	Mean height (inches)	Standard deviation	Coefficient of variation
DAVIS, CALIF.			
F_2 hybrid	52.43±0.09	3.806±0.061	7.259±0.116
Kota	52.58± .25	2.323± .175	4.418± .333
Hard Federation	45.31± .38	3.517± .269	7.762± .593
ST. PAUL, MINN.			
F_2 hybrid	39.48± .10	3.553± .071	8.999± .180
Kota	43.08± .34	3.013± .240	8.994± .556
Hard Federation	32.72± .48	4.064± .343	12.421±1.047
MANDAN, N. DAK.			
F_2 hybrid	34.11± .05	3.144± .065	9.217± .190
Kota	36.40± .19	2.599± .137	7.140± .376
Hard Federation	26.69± .28	3.379± .195	12.660± .732

The frequency distribution shown in Table XVII at Davis, Calif., indicates no maternal influence on height of plant in the reciprocal crosses. The mean heights and their difference, together with their probable errors, are as follows:

Kota × Hard Federation	52.28±0.15
Hard Federation × Kota	52.52± .12
Difference	.24± .19

The difference of 0.24 ± 0.19 of an inch is not only small but not significant as it is only 1.26 times its probable error, indicating odds of about 1.5 : 1.

Evidence that tall plants are dominant is shown by all F_2 data. At the three points the hybrids tend to the tallness of the Kota parent. The variability of the hybrids in comparison with the parents is of interest. Table XVII shows the F_2 progeny to exceed Kota in variability at all three points but to be exceeded in variability by the short Hard Federation parent. The disparity of numbers for the parent reduces the significance of differences in variability. The height is shown to decrease in relation to increasing unfavorable conditions, such as rust and drought.

Under conditions of both rust and drought, F_3 material was studied further in 1923 at Mandan, N. Dak. In all, 726 hybrid plants were measured for height, among 433 F_2 families grown. At least one plant was measured from each family and in the most promising rows several plants were measured. These were the same as those labeled for date of heading, the object being to obtain both early and tall plants. The data obtained at Mandan in F_3 are given in Table XVIII and graphically in Figure 4.

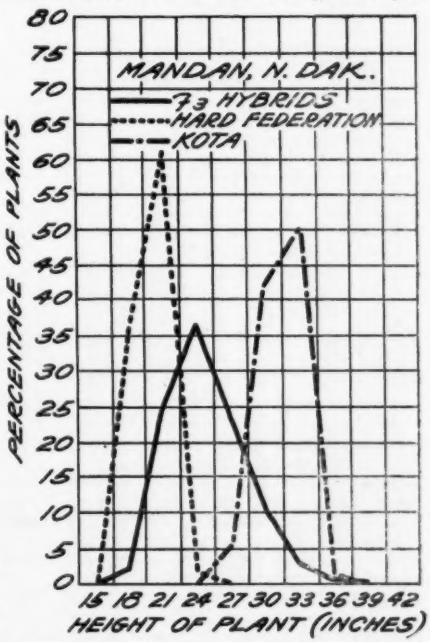


FIG. 4.—Frequency distribution, by height of plant, of F_3 selections and of the Kota and Hard Federation parents at Mandan, N. Dak., in 1923

TABLE XVIII.—*Height of 726 F_3 plants of the Kota-Hard Federation cross, in comparison with the parents, when grown at Mandan, N. Dak., in 1923*

Frequency distribution by height classes (inches)	F_3 hybrid		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
18	18	2.5	35	36.8		
21	174	24.0	58	61.1		
24	268	36.9	2	2.1		
27	170	23.4			4	5.3
30	74	10.2			32	42.7
33	20	2.8			38	50.7
36	2	.3			1	1.3
Total	726	100.1	95	100.0	75	100.0

A severe June drought occurred at Mandan, causing a shortening of both hybrids and parents. Rains early in July enabled late varieties or late-sown wheat to reach a more normal height. This droughty condition affected the F_3 results. It will be noted that the majority of F_3 hybrids tend to the shortness of the Hard Federation parent, which is the reverse of the F_2 results. It is concluded that tallness may be partially dominant but due principally to heterosis and easily influenced by different environmental conditions. As most of the selections were as early as Hard Federation, the desired increase in height is being obtained in some cases even under conditions of severe drought. The average height of the F_3 selections was 25 inches, that of Hard Federation 20 inches, and that of Kota 31 inches. The hybrids were more than twice as variable as the parents, the coefficient of variability for the hybrids and parents being as follows:

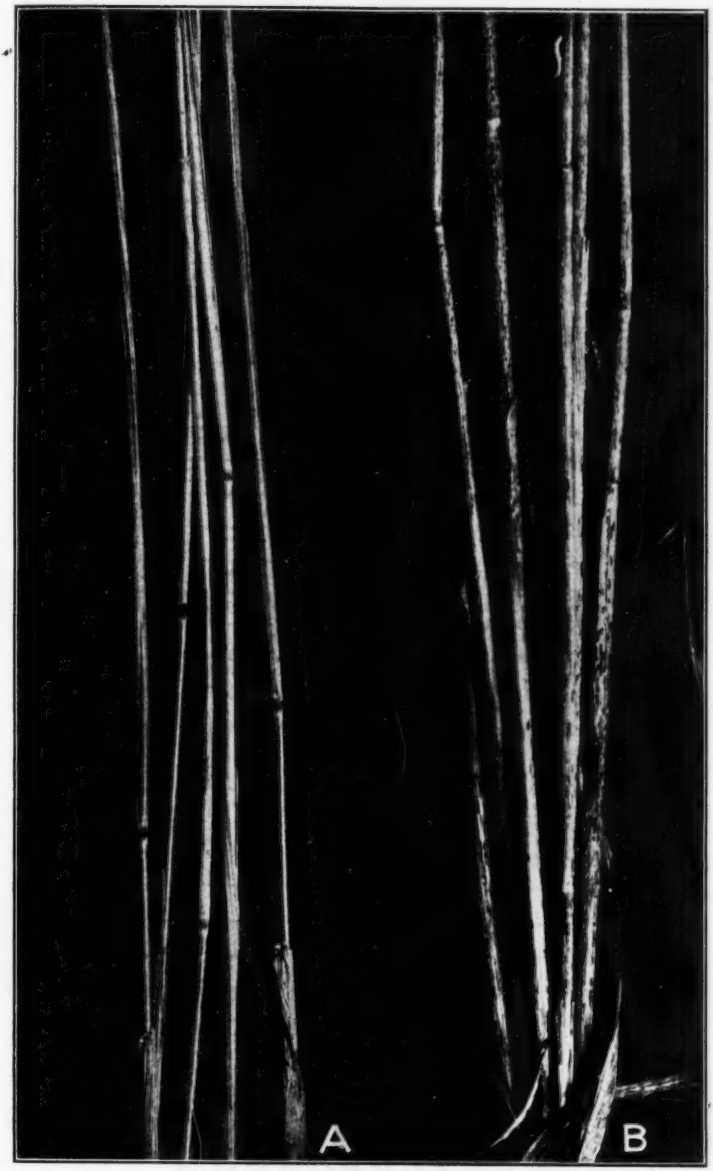
F_3 hybrids	13.365 ± 0.237
Hard Federation	$6.823 \pm .334$
Kota	$5.624 \pm .310$

STEM-RUST INFECTION

Resistance to stem rust, *Puccinia graminis tritici*, is the most economically important physiological character studied in this cross, as severe losses from stem-rust infection are common in the northern spring-wheat section.

Several investigators, both plant breeders and plant pathologists, are studying resistance to this disease. Hayes and Stakman (*21*) have reviewed the investigations of these workers. Stakman and Levine (*33*) have shown that there are 37 physiologic forms of stem rust of wheat which are identified by their parasitic action on 12 differential hosts. This is thought to account for much of the disagreement in field results. Aamodt (*2*), in a study of Kanred × Marquis, found Kanred immune to several of these specialized forms and susceptible to others. In greenhouse studies with the immune strains, immunity was found to be dominant. There were no intermediates. The experiment indicated that the reaction to the several forms was inherited as a unit. Hayes and Aamodt (*20*) have shown under field conditions that in the Marquis-Kota cross the resistance of Kota was recessive. No definite genetic ratio was determined, resistant F_3 families occurring in the proportion of about 1 to 7.73. The resistant strains were as resistant as Kota.

In the Kota-Hard Federation cross, the present study in the field also shows susceptibility to be dominant and resistance recessive. At St. Paul the plants were inoculated with nine different specialized forms of stem rust common to the northern spring-wheat region. At Mandan, N. Dak., natural infection occurred and it is not known how many forms of rust were present there. No rust occurred at Davis, Calif. Abundant infections were obtained at both St. Paul and Mandan, but the injury was not great at either place. Infection at Mandan was a little more abundant than at St. Paul. Rust notes were taken on individual plants at both points. The data are given in Table XIX and graphically shown in Figure 5. Extreme degrees of infection obtained on F_2 plants grown at Mandan are shown in Plate 3. The infection on the resistant plant was recorded as 2 per cent and that on the susceptible plant as 95 per cent. Degrees of infection intermediate between these two extremes were obtained on the hybrid material at both points.



Inheritance in Kota—Hard Federation Crosses Plate 3

Extreme degrees of stem-rust infection of F_2 hybrids of the Kota-Hard Federation cross at Mandan, N. Dak., in 1922; (A) 2 per cent of infection and (B) 95 per cent of infection

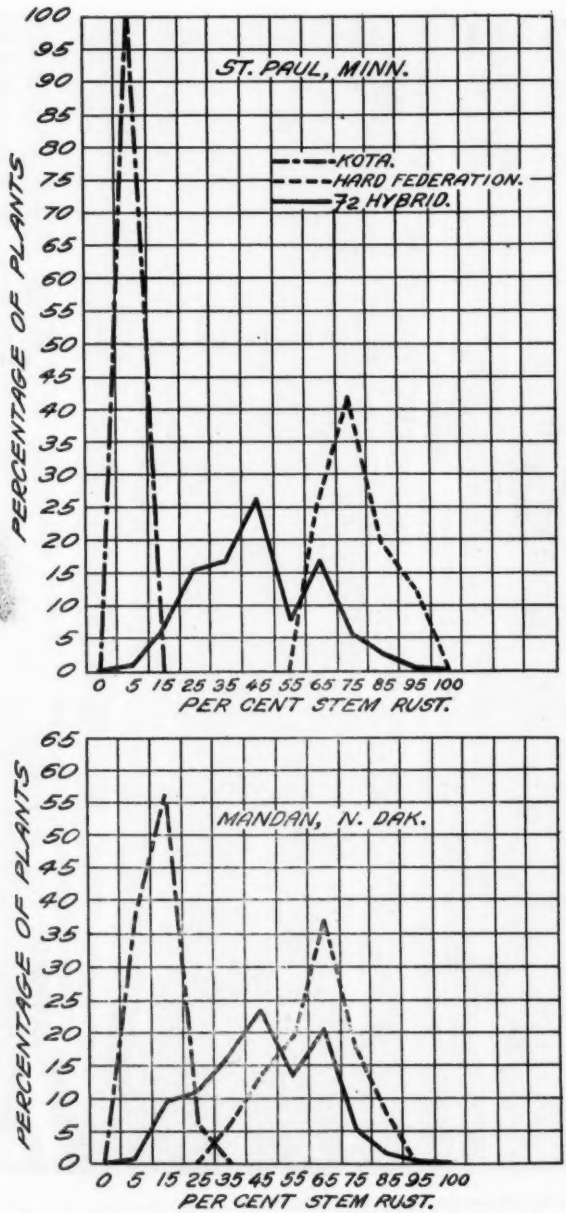

ST. PAUL, MINN.
KOTA.
HARD FEDERATION.
72 HYBRID.
PERCENTAGE OF PLANTS
0 5 15 25 35 45 55 65 75 85 95 100
PER CENT STEM RUST.
MANDAN, N. DAK.
PERCENTAGE OF PLANTS
0 5 15 25 35 45 55 65 75 85 95 100
PER CENT STEM RUST.

FIG. 5.—Frequency distribution, by percentage of stem-rust infection, of F_2 hybrids and of the Kota and Hard Federation parents at St. Paul, Minn., and Mandan, N. Dak., in 1922

TABLE XIX.—*Segregation of 1722 F_2 plants of the Kota-Hard Federation cross, in comparison with parents, into 10 per cent infection classes for stem-rust infection, when grown at St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and rust infection classes (per cent)	Number and percentage of plants on stem-rust infection					
	F_2 hybrids		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
ST. PAUL, MINN.						
5	9	1.6			36	100.0
15	40	7.1				
25	85	15.1				
35	92	16.3				
45	150	26.6				
55	43	7.6				
65	96	17.0	8	25.8		
75	31	5.5	13	42.0		
85	16	2.8	6	19.4		
95	2	.4	4	12.9		
Total	564	100.0	31	100.1	36	100.0
MANDAN, N. DAK.						
5	7	.6			31	37.8
15	109	9.4			46	56.1
25	115	9.9			5	6.1
35	173	14.9	4	5.9		
45	274	23.7	9	13.2		
55	160	13.8	13	19.1		
65	235	20.3	25	36.8		
75	63	5.4	12	17.6		
85	20	1.7	5	7.5		
95	2	.2				
Total	1,158	99.9	68	100.1	82	100.0

TABLE XX.—*Segregation of 6,052 F_2 plants of Kota-Hard Federation and reciprocal crosses into resistant and susceptible classes for stem-rust infection, when grown at St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and cross	Number of F_1 families	Number and percentage of F_2 plants				Total number	Deviation from 15:1	Probable error
		Susceptible		Resistant				
		Number	Percentage	Number	Percentage			
ST. PAUL, MINN.								
Kota×Hard Federation	30	864	92.0	75	8.0	939	16	5.00
Hard Federation×Kota	40	963	93.3	69	6.7	1,032	4	5.24
Total	70	1,827	92.7	144	7.3	1,971	21	7.24
MANDAN, N. DAK.								
Kota×Hard Federation	28	1,946	93.2	143	6.8	2,089	12	7.48
Hard Federation×Kota	38	1,876	94.2	116	5.8	1,992	9	7.28
Total	66	3,822	93.7	259	6.3	4,081	4	10.46
Grand total	75	5,649	93.3	403	6.7	6,052	25	12.70

The rust notes taken on individual F_2 plants shown in Table XIX were on the same plants labeled for date of heading and measured for height. These were of the Kota × Hard Federation cross. Kota showed resistance, with an average of only 3.5 per cent infection at St. Paul and 12 per cent at Mandan. Hard Federation was susceptible, with an average infection of

77 per cent at St. Paul and 68 per cent at Mandan. The F_2 hybrids showed from 5 to 95 per cent of infection at both points, averaging 45 per cent at St. Paul and 46 per cent at Mandan. There was no distinct separation between resistant and susceptible strains.

Additional material was studied for resistance, upon which individual rust notes were recorded only on plants about as resistant as the Kota parent or having an estimated infection of 15 per cent or less. This was thought to be about the maximum amount of infection which could occur without damage. By taking this estimated infection of 15 per cent or less as resistant and grouping the remainder as susceptible at both St. Paul and Mandan, F_2 results were found to agree very closely to a 2-factor hypothesis. The data obtained are shown in Table XX.

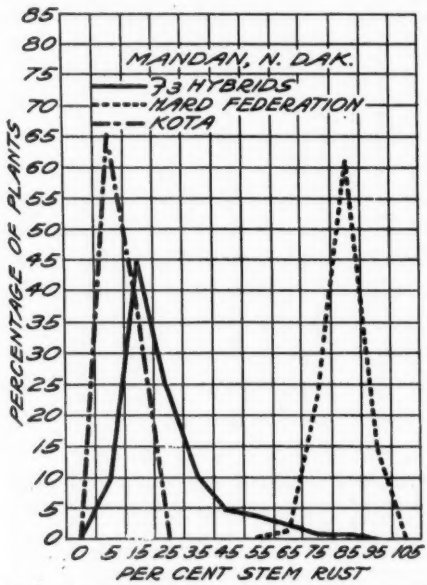

MANDAN, N. DAK.
F3 HYBRIDS
HARD FEDERATION
KOTA
PERCENTAGE OF PLANTS
PER CENT STEM RUST
0 5 15 25 35 45 55 65 75 85 95 105
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85

FIG. 6.—Frequency distribution, by percentage of stem-rust infection, of F_3 selections and of the Kota and Hard Federation parents at Mandan, N. Dak., in 1923

Table XX shows that, on the arbitrary division made, there is slight evidence of maternal influence. Where the susceptible Hard Federation was used as the female parent, a close fit to the 15:1 ratio was obtained in both cases. Where the resistant Kota was used as the female parent a greater proportion of resistant plants was obtained and at St. Paul the deviation from the expected ratio was greater than three times the probable error. The grand average for both crosses at both stations, however, shows that a very close fit was obtained in F_2 for the assumption that two Mendelian factors are involved for stem-rust resistance in this cross.

At Mandan, N. Dak., in 1923, the 724 F_3 plants, which were labeled for date of heading and measured for height, were examined individually and the infection of stem rust estimated. The data obtained are given in Table XXI and shown graphically in Figure 6.

TABLE XXI.—*Stem-rust infection on 724 F_3 plants of the Kota-Hard Federation and reciprocal crosses, and comparison with the parents, grown at Mandan, N. Dak., in 1923*

Frequency classes in percentage of stem-rust	F_3 hybrid		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
5	68	9.4			49	65.3
15	326	45.0			26	34.7
25	175	24.2				
35	71	9.8				
45	33	4.6				
55	27	3.7				
65	16	2.2	1	1.1		
75	5	0.7	22	23.2		
85	3	0.4	58	61.1		
95			14	14.7		
Total	724	100.0	95	100.1	75	100.0

The average infection of these F_3 hybrids was 23 per cent, compared with 7 per cent for Kota and 84 per cent for Hard Federation. The average infection of Marquis grown in check rows in the same experiment was 49 per cent. Considerable resistance has been obtained in the selected plants, although the average percentage is not as great as that of the Kota parent. However, it is much greater than that of Marquis.

Unfortunately the resistant plants which were separated so that they appeared to segregate in F_2 in a 1:15 ratio were not found to breed true for resistance in the F_3. A large number of the so-called resistant F_2 plants were grown at both St. Paul and Mandan in F_3, and not one could be said to be homozygous for resistance. All of the F_3 material grown at St. Paul and Mandan was examined for resistant plants, and the percentage of these to the total by F_2 frequency classes has been determined. Only resistant strains were grown at St. Paul, while at Mandan both resistant and susceptible strains were grown. The resistant group of F_2 plants noted for stem-rust infection has been classified into 3 per cent classes and the susceptible group into 10 per cent classes. The data on segregation in the F_3 according to these groups and classes are given in Table XXII.

The data for the resistant groups show that there was a much larger proportion of resistant plants at Mandan than at St. Paul. This can be attributed to the earlier and more severe rust epidemic which occurred at St. Paul. At Fargo, N. Dak., where a few of the resistant F_2 selections were grown and where rust was much more severe than at St. Paul, there did not appear to be any F_3 plants which could be classed as resistant or as having the resistance of Kota. No definite data were taken on the material at Fargo. At Mandan, where only fairly severe infection occurred, definite data were taken on F_3 of both the resistant and the susceptible F_2 groups. At St. Paul only the resistant group was grown. When it is divided into five 3 per cent classes, as shown in Table XXII, there is seen to be a general, but not a definite, decrease in the percentage of resistant F_3 plants. The decrease is from 18.8 per cent for the 2 per cent class to 5 per cent for the 14 per cent class. At Mandan there was no general decrease among the five classes of the resistant group. The resistant

TABLE XXII.—*Segregation of 10,042 F_3 plants of the Kota-Hard Federation and reciprocal crosses grown at St. Paul, Minn., and Mandan, N. Dak., in 1923, arranged on the basis of infection of the F_2 resistant and susceptible groups in 1922*

Source, group, and infection class in F_2 (per cent)	Number of F_2 families	Number of F_3 plants			Per cent resistant
		Susceptible	Resistant	Total	
ST. PAUL, MINN.[a]					
Resistant:					
(1-3) 2	2	26	6	32	18.8
(4-6) 5	17	213	38	251	15.1
(7-9) 8	20	291	15	306	4.9
(10-12) 11	48	665	72	737	9.8
(13-15) 14	49	705	37	742	5.0
Total	136	1,900	168	2,068	8.1
MANDAN, N. DAK.					
Resistant:					
(1-3) 2	10	158	84	242	34.7
(4-6) 5	40	773	191	964	19.8
(7-9) 8	27	528	99	627	15.8
(10-12) 11	116	1,987	725	2,712	26.7
(13-15) 14	80	1,449	393	1,842	21.3
Total	273	4,895	1,492	6,387	23.4
Susceptible:					
(16-20) 18	20	449	29	478	6.1
(21-30) 25	31	728	14	742	1.9
(31-40) 35	39	896	22	918	2.4
(41-50) 45	20	474	3	477	.7
(51-60) 55	20	517	3	520	.6
(61-70) 65	14	331	4	335	1.2
(71-80) 75	6	150	0	150	0
(81-90) 85	2	35	0	35	0
Total	152	3,580	75	3,655	2.1
Mandan total	425	8,475	1,567	10,042	15.6

[a] F_3 data at St. Paul were obtained by Olaf S. Aamodt.

group averaged 23.4 per cent of resistant plants at Mandan and only 8.1 per cent at St. Paul.

The susceptible group at Mandan showed that F_2 plants having from 16 to 70 per cent infection produced a few resistant plants. All F_2 plants grown which had 71 per cent or more of infection, did not produce any resistant plants. The susceptible class produced as a whole only 2.1 per cent of resistant plants. Among the entire 10,042 F_3 plants grown at Mandan, 1,567, or 15.6 per cent, were classified as resistant.

Of the 75 F_4 selections grown at Mandan in 1923, 31 were estimated to have an average rust infection of 15 per cent or less. These were all from what appeared to be resistant F_3 plants at St. Paul or Mandan in 1922. Of the 31 only 10 appeared as resistant as Kota (average of 5 per cent), including 4 which were noted to be more resistant. There is evidence, therefore, that F_4 strains can be obtained which are homozygous for stem-rust resistance. Whether they will be as resistant or more resistant than Kota under conditions of very severe rust remains to be determined.

YIELD OF PLANTS

Yield may be considered as a character complex affected by environment and by most of the morphological and physiological characters of the plant. Engledow and Wadham (*10*) state that—

> Cereal yield is controlled by a great number of factors which are themselves complex and imperfectly understood. In approaching the yield problem it is convenient to arrange these in broad categories which may thus be designated: (1) Soil, (2) climate, (3) agricultural practice, (4) disease and damage, (5) botanical variety or form.

Beaven (*3*) concludes that—

> The problem of the cereal breeder is to discover the relation between the different structures of the individual plant and the probable quantity of saleable produce per acre. The predominant factor of productivity in cereals is the seed-forming energy of the individual plants composing the crop.

Yields of F_2 and F_3 plants were obtained in the present study. The plants were definitely spaced, harvested individually, threshed, and the grain weighed to tenths of grams. In the F_2 yields were obtained at St. Paul and Mandan. The data obtained are given in Table XXIII and shown graphically in Figure 7.

TABLE XXIII.—*Segregation of 1,699 F_2 plants of the Kota-Hard Federation crosses, in comparison with their parents, into 1-gram classes for yield of plant, at St. Paul, Minn., and Mandan, N. Dak., in 1922*

Source and yield classes (grams)	Number and percentage of plants					
	F_2 hybrid		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
ST. PAUL, MINN.						
0.5	28	5.2	5	31.2		
1.5	83	15.3	7	43.7		
2.5	91	16.8	2	12.5	1	5.6
3.5	97	17.9	2	12.5	1	5.6
4.5	82	15.1			2	11.1
5.5	67	12.4			2	11.1
6.5	44	8.1			4	22.2
7.5	24	4.4			2	11.1
8.5	13	2.4			3	16.7
9.5	7	1.3			2	11.1
10.5	3	.6			1	5.6
13.5	1	.2				
15.5	1	.2				
Total	541	99.9	16	99.9	18	100.1
MANDAN, N. DAK.						
0.5	16	1.4	10	23.8	1	3.3
1.5	83	7.2	14	33.3	2	6.7
2.5	196	16.9	11	26.2	10	33.3
3.5	278	24.0	5	11.9	8	26.7
4.5	264	22.8	2	4.8	6	20.0
5.5	166	14.3			2	6.7
6.5	93	8.0			1	3.3
7.5	35	3.0				
8.5	17	1.5				
9.5	5	.4				
10.5	3	.3				
11.5	1	.1				
12.5	1	.1				
Total	1,158	100.0	42	100.0	30	100.0

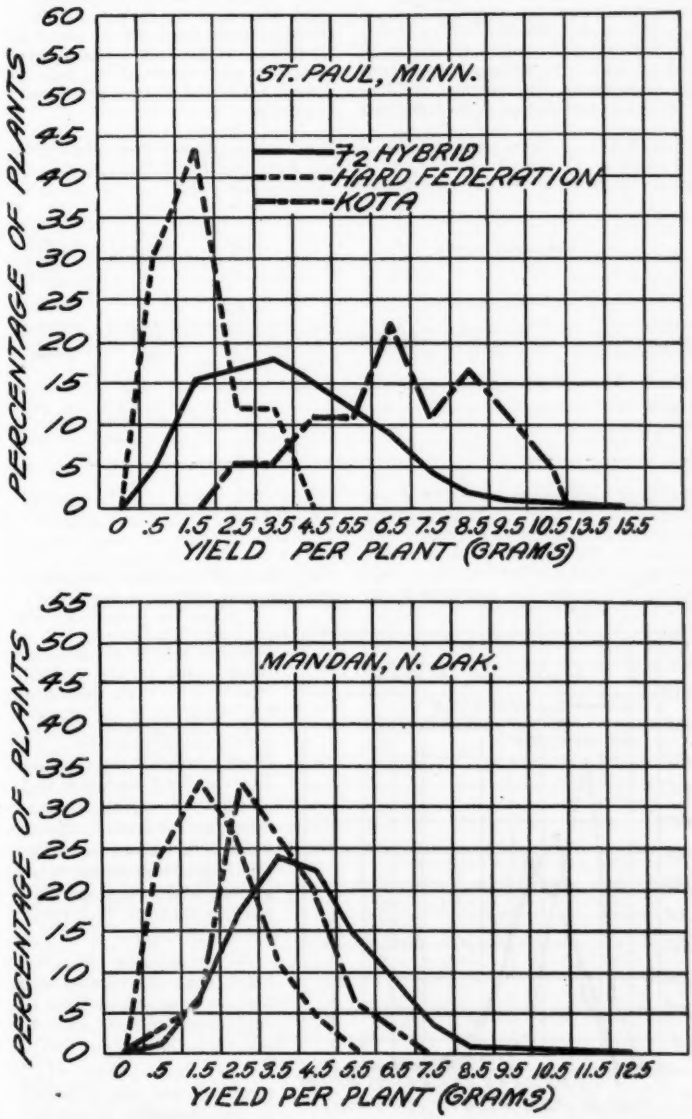

ST. PAUL, MINN.
F_2 HYBRID
HARD FEDERATION
KOTA
PERCENTAGE OF PLANTS
0 5 10 15 20 25 30 35 40 45 50 55 60
0 .5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 13.5 15.5
YIELD PER PLANT (GRAMS)
MANDAN, N. DAK.
PERCENTAGE OF PLANTS
0 5 10 15 20 25 30 35 40 45 50 55
0 .5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5
YIELD PER PLANT (GRAMS)

FIG. 7.—Frequency distribution, by yield of plant, of F_2 hybrids and of the Kota and Hard Federation parents at St. Paul, Minn., and Mandan, N. Dak., in 1922

99178—25†——3

The data show a wide range in variation in the yield of F_2 plants. The number of parent plants threshed for comparison is small, especially at St. Paul. The average yield, standard deviation, and coefficient of variation of F_2 hybrids and parents are shown in Table XXIV. It appears important that at Mandan the average yield of the hybrids exceeds that of both parents and that at both points the coefficient of variation is greater for the hybrids than for Kota, the high-yielding parent. Because of the disparity of numbers of the parents and of the low mean yield of Hard Federation the standard deviation apparently is the best measure of variability. It shows at both points that the hybrids are considerably more variable than either parent.

At Mandan, N. Dak., in 1923, the threshed grain from 900 F_3 plant selections was weighed and the yields are compared with those of the parents in Table XXV and shown graphically in Figure 8.

TABLE XXIV.—*Mean yield, standard deviation, and coefficient of variation for yield of plants of F_2 hybrids, and of the parents Kota and Hard Federation varieties, grown at St. Paul, Minn., and Mandan, N. Dak., in 1922*

Station and material	Mean yield	Standard deviation	Coefficient of variation
ST. PAUL, MINN.	*Grams*		
F_2 hybrid	3.97±0.06	2.215±0.045	55.793±1.144
Kota	6.78±.34	2.129±.239	31.401±3.530
Hard Federation	1.56±.16	.966±.115	61.923±7.383
MANDAN, N. DAK.			
F_2 hybrid	4.15±.03	1.713±0.24	41.277±.579
Kota	3.37±.16	1.284±.112	38.101±3.318
Hard Federation	1.90±.12	1.114±.082	58.632±4.315

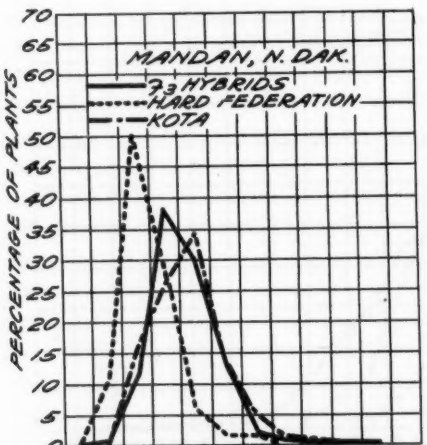


FIG. 8.—Frequency distribution, by yield of plant, of F_3 selections and of the Kota and Hard Federation parents at Mandan, N. Dak., in 1923

The data show that in segregation for yield the F_3 selections made in 1923 were less variable, in comparison with the parent than were the F_2 selections. The mean yield, standard deviation, and coefficient of variation for the F_3 hybrids and the parents are shown in Table XXVI.

Table XXVI shows that the mean yield of the hybrids is slightly but not significantly less than that of Kota, the higher yielding parent, the difference being 0.19±0.10 grams. The standard deviation and coefficient of variation also are less than for Kota. The mean yield of a number of Marquis plants grown as checks was 3.03 grams, which was slightly but not significantly less than the hybrid selections.

As practically all the F_3 plant rows were heterozygous for one or another of the plant characters studied, none of the rows was harvested for yield. As the mean yield of each selection was not obtained, it is not possible to show the segregation for yield in F_3 according to F_2 classes.

TABLE XXV.—*Yield of 900 F_3 plants of the Kota-Hard Federation and reciprocal crosses, in comparison with that of the parents, grown at Mandan, N. Dak., in 1923*

Frequency classes yield (grams)	F_3 hybrids		Hard Federation		Kota	
	Number	Percentage	Number	Percentage	Number	Percentage
0.5	14	1.6	11	11.6		
1.5	114	12.7	48	50.5	12	16.4
2.5	346	38.4	26	27.4	20	27.4
3.5	274	30.4	6	6.3	25	34.2
4.5	115	12.8	2	2.1	10	13.7
5.5	22	2.4	2	2.1	4	5.5
6.5	10	1.1			1	1.4
7.5	4	0.4			1	1.4
8.5	1	0.1				
Total	900	99.9	95	100.0	73	100.0

TABLE XXVI.—*Mean yield, standard deviation, and coefficient of variation for yield of plants of F_3 hybrids and for the Kota and Hard Federation parent varieties, grown at Mandan, N. Dak. in 1923*

Station and material	Mean yield	Standard deviation	Coefficient of variation
	Grams		
F_3 hybrids	3.05±0.03	1.119±0.018	36.689±0.583
Kota	3.24± .10	1.250± .070	38.580±2.154
Hard Federation	1.93± .07	.991± .048	51.347±2.512

SEGREGATION IN THE F_4 FOR FACTORS OF QUALITY

As the quality of a new hard red spring wheat is of importance equal to that of yield, it is very desirable to determine at the earliest practical time the segregation of hybrid selections for important quality-affecting factors. In the present investigations an effort is being made to study certain quality factors, starting with grain from F_4 selections of the hybrids. Lack of funds for this work limits the number of determinations, so the results here given can be considered only as preliminary.

From the 75 F_4 selections grown at Mandan in 1923, grain from 30 of the most promising was selected for making tests for four quality factors. These are (1) viscosity, for the quality of the gluten; (2) crude protein of wheat and flour, for the quantity of gluten; (3) gasoline color reaction, for the color of the flour; and (4) ash, for quantity of ash in the flour. The quality and quantity of the gluten in hard red spring wheat is of great importance to the trade. Their objection to the yellowish color and high ash content of Kota also makes it desirable to give careful consideration to segregation for these factors in hybrids having Kota as a parent.

VISCOSITY

Viscosity determinations have been suggested recently by several workers as a means of approximately evaluating the relative quality of the gluten in flours, without baking. Principal among the studies in this field of colloidal chemistry are those by Ostwald (*25*), and Luers and Ostwald (*23*) of Germany, and by Weaver and Goldtrap (*37*), Gortner and Sharp (*16*), and Sharp and Gortner (*29*) in the United States. A standard method has not yet been evolved.

The writer conducted some preliminary trials (unpublished) under the direction of Dr. C. H. Bailey at the University of Minnesota, using the improved MacMichael viscosimeter. Twenty grams of flour of each sample were mixed with 100 cc. of distilled water and poured into 900 cc. of water. The flour particles were kept in suspension for 50 minutes by intermittent agitation. After settling for 10 minutes the extract was decanted and 500 cc. of water added to the residue and agitated. The suspension again was allowed to settle and decanted to 100 cc. The washing removed a large part of the soluble electrolytes. The 100 cc. of residue was poured into the bowl of the MacMichael viscosimeter.

A 2-centimeter cylindrical bob was used, suspended by a No. 30 wire. The viscosity was determined at once and after the addition of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 cc. of normal lactic acid.

One hundred and twelve samples were studied, including 50 varieties of wheat representing the five commercial classes, Hard Red Spring, Durum, Hard Red Winter, Soft Red Winter, and White, obtained from 11 agricultural experiments stations in 10 Western States. The wheat samples had been milled and baked previously in the Milling Investigations Laboratory of the Grain Division of the Bureau of Agricultural Economics, United States Department of Agriculture, at Washington, D. C.

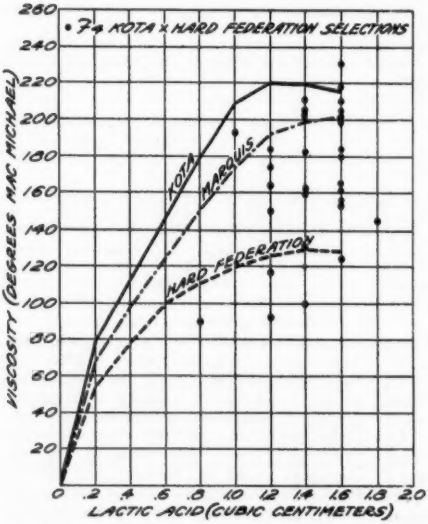


FIG. 9.—Viscosity curves for the Kota, Marquis, and Hard Federation varieties, and maximum viscosity for 30 F_4 Kota × Hard Federation selections grown at Mandan, N. Dak., in 1923

The viscosity as determined by constant readings, in degrees MacMichael, was correlated with loaf volume, in cubic centimeters, and the important and significant positive correlation 0.368 ± 0.055 obtained. The viscosity of the same samples correlated with crude-protein content of the wheat (N×5.7, 13.5 per cent moisture) gave a less important correlation of 0.287 ± 0.058. The correlation between crude protein and loaf volume for the same 112 samples was negative, -0.066 ± 0.063 and not important or significant. These experiments, therefore, confirmed the conclusions of previous studies that the viscosity determinations indicated strength of gluten, although there was also a fairly good correlation between viscosity and crude-protein content.

This preliminary study led to a trial of the viscosity test for determining the quality of promising F_4 selections in the present hybrid study. The limited amount of grain produced from a plant selection prevents the making of a baking test. Seventy-five grams of wheat of each of 30 F_4 selections were milled as uniformly as possible and produced approximately 35 grams of straight flour. Because of the small amount of grain, uniform milling was very difficult and the results were not entirely satisfactory. The flour obtained was tested for viscosity, crude protein, gasoline color, and ash. The viscosity trials were conducted by the writer by the method decribed above. Flour from the Kota and Hard Federation parent varieties, as well as Marquis, grown in check rows, were tested in duplicate in a similar manner. The viscosities obtained with these varieties, with increasing amounts of lactic acid until maximum viscosity was reached, are shown in Figure 9. The distribution of the maximum viscosity of each of the 30 hybrid strains is indicated by dots in the Figure. The segregation by 20-degree frequency classes also is shown in Table XXVII.

The data show a wide segregation with most of the hybrids intermediate between the parents, although one exceeded Kota and five were lower than Hard Federation. The average maximum viscosity for the 30 hybrids was 170 degrees MacMichael, compared with averages of 220, 203, and 129 degrees MacMichael, respectively, for duplicate samples of Kota, Marquis, and Hard Federation. The disparity in numbers prevents any conclusion regarding the mode of inheritance of strength of flour, but there is distinct evidence of segregation and the viscosity test furnishes a promising method of attack by which to breed wheat for gluten quality.

TABLE XXVII.—*Segregation of 30 F_4 selections of the Kota-Hard Federation and reciprocal crosses, together with the parents and Marquis, for viscosity in degrees MacMichael, at Mandan, N. Dak., in 1923*

Class	F_4 hybrids		Hard Federation	Kota	Marquis
	Number	Percentage	Number	Number	Number
100	3	10.0			
120	2	6.7	1		
140	2	6.7	1		
160	8	26.7			
180	5	16.7			
200	6	20.0			2
220	3	10.0		2	
240	1	3.3			
Total	30	100.1	2	2	2

CRUDE-PROTEIN CONTENT

The quantity of crude protein in the wheat and flour is a standard index of the quantity of gluten. Determinations in this study were made by the method described by Shollenberger, Marshall, and Coleman (*31*) (N.×5.7, basis 13.5 per cent moisture) in the Research Laboratory of the Grain Division of the Bureau of Agricultural Economics. The results obtained on crude protein in the kernels are shown in Table XXVIII.

The data show evidence of segregation in crude-protein content of the kernels. The small numbers involved do not permit of any definite conclusion, but in general it appears that high crude-protein wheats can be obtained from this cross as most of the selections are equal or superior to Kota. Twenty-nine hybrid selections averaged 16.1 per cent crude protein in the wheat, while duplicate samples of Kota, Marquis, and Hard Federation averaged 15.9, 15.7, and 14.7 per cent, respectively.

TABLE XXVIII.—*Segregation of 29 F_4 selections of the Kota-Hard Federation and reciprocal crosses, together with the parents and Marquis, for crude protein of the kernels, at Mandan, N. Dak., in 1923*

Classes by crude protein content (per cent)	F_4 hybrids		Hard Federation	Kota	Marquis
	Number	Percentage	Number	Number	Number
14.5			1		
15.0	3	10.3	1		
15.5	6	20.7			1
16.0	11	37.9		2	1
16.5	4	13.8			
17.0	2	6.9			
17.5	3	10.3			
Total	29	99.9	2	2	2

The results obtained on crude protein in the flour are given in Table XXIX.

The data on crude protein in the flour also show evidence of segregation and, while the disparity of numbers prevents definite conclusions, it appears probable that in this cross hybrid selections can be obtained which exceed the parents in the quantity of their gluten. Twenty-eight hybrids averaged 15.6 per cent crude protein in the flour while duplicate samples of Kota, Hard Federation, and Marquis averaged 14.9, 14.6, and 14.3 per cent, respectively.

TABLE XXIX.—*Segregation of 28 F_4 selections of the Kota-Hard Federation and reciprocal crosses, together with the parents and Marquis, for crude protein of the flour, at Mandan, N. Dak., in 1923*

Classes by crude protein content (per cent)	F_4 hybrids		Hard Federation	Kota	Marquis
	Number	Percentage	Number	Number	Number
14.0	2	7.1	1	1	1
14.5	1	3.6			1
15.0	7	25.0	1		
15.5	10	35.7		1	
16.0	5	17.9			
16.5	1	3.6			
17.0	1	3.6			
17.5	0	.0			
18.0	1	3.6			
Total	28	100.1	2	2	2

FLOUR COLOR

The gasoline color test is considered the best practicable method of determining the color of flour. The method used in this study is described by Shollenberger, Marshall, and Coleman (*31*). A limited number of preliminary experiments have shown Kota to exceed Marquis in gasoline color value. No comparison had been made between Kota and Hard Federation. Because of the popular demand for white flour and bread there is a prejudice against flours with a creamy or yellowish color containing more carotin. As the trade finds this character objectionable in Kota it is important to determine if there is segregation for this character in Kota hybrids.

Gasoline color values have been determined on the flours of the 30 F_4 hybrids and on the duplicate samples of Kota, Hard Federation, and Marquis, previously discussed. The data are summarized by frequency classes in Table XXX.

The data show considerable segregation in the hybrids. The limited data do not show Kota to exceed Hard Federation or Marquis in color of flour and are not in accord with preliminary experiments and commercial findings. However, a considerable number and percentage of the hybrids have less color than the parents and Marquis, indicating segregation in the desired direction and the possibility of obtaining the desired results. The average gasoline color value for the 30 F_4 hybrids was 1.79 and that of Hard Federation, Kota, and Marquis 2.01, 1.74, and 1.94, respectively.

TABLE XXX.—*Segregation of 30 F_4 selections of the Kota-Hard Federation and reciprocal crosses, together with the parents and Marquis, for gasoline color value, at Mandan, N. Dak., in 1923*

Classes by gasoline color value	F_4 hybrids		Hard Federation	Kota	Marquis
	Number	Per cent	Number	Number	Number
0.90	2	6.7			
1.10	0				
1.30	4	13.3			
1.50	2	6.7			
1.70	5	16.7		1	
1.90	9	30.0	1	1	1
2.10	5	16.7	1		1
2.30	3	10.0			
Total	30	100.1	2	2	2

ASH IN FLOUR

The amount of ash in flour is an important factor in the grading and selling of flour. A considerable proportion of the flour trade buys flour on its ash content, as in general it furnishes a basis for judging the extraction in milling. Certain varieties, however, such as Kota, have a relatively high ash as an inherent quality. While a larger quantity of nutritive ash is not objectionable in itself, a variety which normally has a higher ash than the class average is at some disadvantage under present flour standards.

Experiments reported by Clark and Shollenberger (7) have shown Kota to have a significantly higher ash content than that of Marquis. Table IV shows Hard Federation to average less than Marquis in ash content. In the present study of hybrids the ash content of the flour could not be very accurately determined, due to the small amount of grain milled and the nonuniformity of milling. It seemed desirable, however, to determine the ash content of the flour available to see if segregation for ash content appeared to occur in the hybrids. The data obtained are given in Table XXXI.

TABLE XXXI.—*Segregation of 29 F_4 selections of the Kota-Hard Federation and reciprocal crosses, together with the parents and Marquis, for ash in flour, at Mandan, N. Dak., in 1923*

Ash in flour (class)	F_4 hybrids		Hard Federation	Kota	Marquis
	Number	Percentage	Number	Number	Number
0.55	2	6.9			
0.65	12	41.4		1	
0.75	9	31.0	2	1	
0.85	3	10.3			1
0.95	1	3.4			
1.05	1	3.4			
1.15	1	3.4			
Total	29	99.8	2	2	1

It will be seen that the ash content is unusually high for both hybrids and varieties. This is largely due to the method of milling, the small amount of wheat used making it difficult to keep part of the germ and shorts from passing into the flour. The wheat also was not scoured, which undoubtedly helped to increase the ash. The higher ash content of Marquis and Hard Federation over that of Kota, may be due in part to their shrunken kernels and low weight, due to injury from stem rust.

The data show considerable differences in ash content and more than should be due to differences in milling. There is evidence, therefore, that ash content is inherited as other quantitative characters, and that if sufficient numbers were studied, the mode of its inheritance could be determined and selections made which would have an inherently low ash.

CORRELATION OF CHARACTERS IN THE F_2 AND F_3

An inheritance study of the characters discussed would not be sufficiently inclusive without some knowledge of the effect the more important characters have on each other and on yield. The amount of correlation which is found between the different characters should serve as an important guide for the making of further selections. Coefficients have been determined for the correlation of several characters with date of heading and yield. Those were calculated by the product moment method for coefficient of correlation. The correlations of height and stem-rust infection with date of heading, and date of heading, height, stem-rust infection, and awn classes with yield, combine the principal data on drought and rust obtained in this study.

Time of maturity is important in determining the ability of a variety to evade or resist drought and rust. It has not been determined how early wheats may mature in the northern spring-wheat area before yield is reduced. High yield may be sacrificed with increasing earliness of varieties. Real resistance to both rust and drought probably is more desirable than earliness. Both might combine to make for maximum success.

DATE OF HEADING AND HEIGHT OF PLANT

The correlation between date of heading and height of plant has been studied in F_2 material grown at Davis, Calif., St. Paul, Minn., and Mandan, N. Dak., in 1922, and F_3 material grown at Mandan, N. Dak., in 1923. The Mandan data are given in Tables XXXII and XXXIII.

height of plant was negative and not important or significant at Davis, Calif., under very favorable conditions, but positive, with increasing importance and significance, under increasingly unfavorable conditions at St. Paul, Minn., and Mandan, N. Dak. In both F_2 and F_3 under droughty conditions at Mandan there was an important and significant correlation between date of

TABLE XXXII.—*Correlation between date of heading and height of plant in F_2 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1922*

Height of plant (inches)	Date of heading										Total
	June			July							
	26	28	30	2	4	6	8	10	12	14	
18							1				1
21		1	1		1						3
24		1		2	1	1					5
27		6	7	3	6	1		1			24
30		36	39	18	24	21	6	1			145
33	3	92	118	65	73	47	12	5	1		416
36		64	76	53	65	54	25	7	5	2	351
39	1	5	11	10	23	21	19	7	1	3	101
42			1	3	4	9	1	3			21
45							1				1
Total	4	205	253	154	197	154	65	24	7	5	1,068

$r = 0.250 \pm 0.019$

TABLE XXXIII.—*Correlation between date of heading and height of plant in F_3 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1923*

Height of plant (inches)	Date of heading							Total
	June				July			
	20	23	26	29	2	5	8	
18	3	7	9					19
21	24	85	61	4				174
24	23	114	114	10	3	1		265
27	8	45	94	9	8	1	2	167
30		12	39	15	6	3		75
33		2	7	3	6	1		19
36					2			2
Total	58	265	324	41	25	6	2	721

$r = 0.410 \pm 0.021$

A summary of the coefficients obtained is as follows:

F_2, 1922:
- At Davis, Calif.—0.083 ± 0.023
- At St. Paul, Minn. .131 ± .029
- At Mandan, N. Dak. .250 ± .019

F_3, 1923:
- At Mandan, N. Dak. .410 ± .021

It will be noted that in F_2 the correlation between date of heading and

heading and height of plant. The early plants more often were found to be short and the late plants to be tall. While the results at Davis indicate that the Mandan results are largely due to environmental conditions, random selection of early plants at Mandan would, to a certain degree, lead to the selection of short plants as well.

DATE OF HEADING AND STEM-RUST INFECTION

The effect of earliness on infection of stem rust is a problem of considerable economic importance. Correlations between date of heading and stem-rust infection have been studied in F_2 material of the Kota-Hard Federation crosses at St. Paul, Minn., and Mandan, N. Dak., in 1922, and F_3 material at Mandan in 1923. The Mandan F_2 data are given in Table XXXIV.

TABLE XXXIV.—*Correlation between date of heading and percentage of stem-rust infection in F_2 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1922*

Stem-rust infection (per cent)	Date of heading										Total
	June			July							
	26	28	30	2	4	6	8	10	12	14	
5		4	1	1	1						7
15		42	31	9	12	2	1				97
25	1	30	30	16	13	16	2	1			109
35	1	27	53	24	28	23	6	5	1		168
45		45	60	45	46	36	11	5	1	1	250
55	1	27	33	21	30	22	12	5			151
65	1	26	36	28	48	36	23	7	3	2	210
75		4	5	8	16	12	7		2	2	56
85			4	2	2	6	2	1			17
95					1		1				2
Total	4	205	253	154	197	153	65	24	7	5	1,067

$r = 0.311 \pm 0.019$

The coefficients obtained are summarized as follows:

F_2, 1922:
At St. Paul, Minn. 0.093 ± 0.029
At Mandan, N. Dak. $.311 \pm .019$
F_3, 1923:
At Mandan, N. Dak. $.156 \pm .025$

A significant positive correlation was found between date of heading and stem-rust infection in three instances. The coefficient was not large at St. Paul, but a fairly high degree of correlation was indicated at Mandan in both years. The wheat in 1922 was later in maturing at Mandan than at St. Paul, due to later seeding and being farther north, and rust may have had as good a chance to infect the early plants as the late ones. On the other hand, there probably was more rust inoculum present in the latter part of the ripening period, so that some of the early plants may have partly escaped. Selections of rust-resistant plants, therefore, must be thoroughly tested to be certain that they are resistant rather than escaping. A few fairly late plants in both F_2 and F_3 appeared resistant at Mandan.

YIELD AND DATE OF HEADING

Productiveness or yield is the desired result of wheat breeding. Other characters are important in so far as they affect yield. Quality is important with high yield. The principal characters previously discussed which could affect production are now studied for correlation with yield.

The effect of time of maturity on yield usually is important in the northern spring-wheat area. The aim of the breeder is to produce just as early a wheat as can be grown without sacrificing productiveness. Data on correlations between date of heading and yield of plant were obtained in F_2 from St. Paul, Minn., and Mandan, N. Dak., in 1922, and in F_3 at Mandan in 1923. The results from Mandan in F_3 are given in Table XXXV.

The coefficients obtained are as follows:

F_2, 1922:
At St. Paul, Minn. $-0.324 \pm .026$
At Mandan, N. Dak. $-0.176 \pm .020$
F_3, 1923:
At Mandan, N. Dak. $-0.193 \pm .024$

A significant negative correlation was found between yield and date of heading under the three conditions. The correlation was most important at St. Paul. At Mandan in both 1922 and 1923 the amount of correlation is not sufficient to be considered very important from a selection standpoint. Early heading selections, however, offer the greater possibilities for high yield.

It seemed desirable to determine the inheritance of date of heading in F_3 in relation to that of F_2. The correlation of 0.758 ± 0.024, obtained from 148 plants and shown in Table XXXVI is very important.

TABLE XXXV.—*Correlation between yield of plant and date of heading of F_3 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1923*

Date of heading		Yield of plant, in grams							Total
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	
June	20	.....	7	12	21	13	5	.....	58
	23	1	21	104	94	33	7	2	262
	26	3	55	129	94	37	5	3	326
	29	1	7	19	11	4	.....	.....	42
July	2	3	6	5	8	2	1	.....	25
	5	2	.....	2	1	1	.....	.....	6
	8	.....	1	1	.....	.....	.....	.....	2
Total		10	97	272	229	90	18	5	721

$r = -0.193 \pm 0.024$

TABLE XXXVI.—*Correlation between date of heading in F_2 and F_3 of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1922 and 1923*

Date of heading, 1923		Date of heading, 1922								Total
		June		July						
		26.5	28.5	0.5	2.5	4.5	6.5	8.5	10.5	
June	20.5	.....	13	.....	1	.....	.....	.....	.....	14
	22.5	5	48	11	4	.....	.....	.....	.....	68
	24.5	.....	10	10	7	3	1	.....	.....	31
	26.5	.....	2	7	6	7	2	1	.....	25
	28.5	.....	.....	.....	3	1	1	1	.....	6
July	.5	.....	.....	.....	.....	.....	.....	1	.....	1
	2.5	.....	.....	.....	.....	.....	.....	2	1	3
Total		5	73	28	21	11	4	5	1	148

$r = 0.758 \pm 0.024$

YIELD AND HEIGHT OF PLANT

From a breeding standpoint it is important to determine whether short or tall plants are more productive. Height also is an important economic factor in wheat production. The aim of the breeder is to produce a variety tall enough to be conveniently harvested with a self-binding harvester and still produce maximum yield. Taller varieties have no particular advantage. They are subject to greater injury from storms and use more soil fertility and moisture. Hard Federation often is too short to be conveniently harvested. Kota, on the other hand, is slightly taller than necessary. Height, therefore, should be given careful consideration while making selections of the progeny. But it is first necessary to know the effect of height on yield. Data on correlations between these factors were obtained in F_2 material at St. Paul, Minn., and Mandan, N. Dak., and F_3 material at Mandan. The Mandan F_2 data are presented in Table XXXVII.

TABLE XXXVII.—*Correlation between yield of plant and height of plant in F_2 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1922*

Height of plant, inches	Yield of plant in grams													Total
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	
18	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
21	.....	1	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	3
24	3	2	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	7
27	3	15	5	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	24
30	3	25	51	45	20	5	3	2	.....	.....	.....	.....	.....	154
33	.....	26	83	136	102	56	22	6	2	1	1	1	.....	436
36	4	14	40	79	97	54	45	16	11	3	2	.....	1	376
39	.....	.....	12	14	32	20	22	10	2	1	.....	.....	.....	113
42	1	.....	3	3	7	8	2	1	2	.....	.....	.....	.....	27
45	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	1
Total	15	83	196	278	259	155	94	35	17	5	3	1	1	1,142

$r = 0.405 \pm 0.017$

A summary of the coefficients is as follows:

F_2, 1922:
At St. Paul, Minn. 0.348 ± 0.025
At Mandan, N. Dak. $.405 \pm .017$
F_3, 1923:
At Mandan, N. Dak. $.288 \pm .023$

Important and significant correlations between yield and height were obtained. Height appears to be of greater importance than any of the other characters studied. As the amount of the correlation was considerably reduced at Mandan in F_3 as compared with F_2, it is possible that the increase is partly expressive of hybrid vigor. There were no particularly high yielding short plants in F_2. Height had more of an effect on yield at Mandan under droughty conditions than at St. Paul under rather humid conditions. Apparently shortness of plant is not correlated with real drought resistance. The correlations are sufficiently large to justify the selection of tall plants instead of short ones.

It is desirable to determine the inheritance of average height of row in F_3 in comparison with height of F_2 plants at Mandan. The correlation of 0.556 ± 0.038 in 152 F_2 plants, given in Table XXXVIII, is both high and significant.

YIELD AND AWNEDNESS

The effect of the awn or its absence on yield already has been discussed. It was shown that the presence of awns was of some importance under droughty conditions. In addition to determining the mean yield of the plants in each awn class, it seems desirable to determine the correlation between awnedness and yield. The Mandan F_3 data are given in Table XXXIX. The awn classes are (1) awnless, (2) apically-awnletted, (3) awnletted, (4) short-awned, and (5) awned.

TABLE XXXVIII.—*Correlation between height of plant in F_2 and in F_3 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1922 and 1923*

Height of row, 1923 (inches)	Height of plant in inches, 1922								Total
	29.5	31.5	33.5	35.5	37.5	39.5	41.5	43.5	
19.5	2	3	1		1				7
21.5	2	2	4	2	1				11
23.5	1	10	12	8	2	1			34
25.5	1	2	8	14	3	3			31
27.5		3	7	8	5	2			25
29.5	1		1	10	10	2	1	1	26
31.5			2	4	4	4	2		16
33.5						2			2
Totals	7	20	35	46	26	14	3	1	152

$r = 0.556 \pm 0.038$

TABLE XXXIX.—*Correlation between yield of plant and awnedness in F_3 material of crosses of Kota and Hard Federation wheats grown at Mandan, N. Dak., in 1923*

Awnedness classes	Yield of plant in grams							Total
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	
1		26	50	31	11	2		120
2	6	40	114	90	37	6	4	297
3	1	12	37	38	9	6	1	104
4		7	31	23	9		1	71
5	3	12	43	48	24	4		134
Total	10	97	275	230	90	18	6	726

$r = 0.104 \pm 0.025$

The coefficients are:

F_2, 1922:
At St. Paul, Minn.. 0.079 ± 0.028
At Mandan, N. Dak. $.051 \pm .021$
F_3, 1923:
At Mandan, N. Dak. $.104 \pm .025$

The correlations are positive but small and hardly significant except in F_3 at Mandan in 1923. The F_2 data show that the presence of awns and their length have but slightly less effect upon the yield under droughty conditions at Mandan than under humid conditions at St. Paul. The F_3 data indicate, although the correlation is small, that preference in the selection of awned plants rather than at random seems justified.

YIELD AND STEM-RUST INFECTION

Stem-rust infection is not necessarily an index to rust damage. The same percentage of stem-rust infection in different years may cause different degrees of damage. An important correlation between rust infection and rust injury may be obtained when rust is the principal limiting yield factor. The years 1922 and 1923 were ones of general rust infection. The damage, however, varied with the time and amount of infection in different localities and with the stage of growth of the wheat plant. A correlation study between the percentages of stem rust and yield of plant furnishes a method of determining rust damage from varying amounts of infection. Data were obtained in this study in F_2 at St. Paul, Minn., and Mandan, N. Dak., and in F_3 at Mandan, N. Dak. The data from F_2 at St. Paul, Minn., in 1922 are given in Table XL.

The coefficients are summarized as follows:

F_2, 1922:
At St. Paul, Minn. -0.082 ± 0.028
At Mandan, N. Dak. $-.009 \pm .020$
F_3, 1923:
At Mandan, N. Dak. $-.042 \pm .025$

The correlations are negative, as expected, but they are small and not significant. The infection of rust that occurred in these experiments, therefore, had little or no effect on yield. An opportunity for selection of resistant plants was offered, however, the importance of which is in no way lessened by the results of these correlations.

It is important to determine how the average infection of F_3 strains is correlated with that of F_2 plants. The data presented in Table XLI show that a large, important, and significant coefficient of 0.674 ± 0.018 was obtained. It may be concluded, therefore, that the resistance to stem rust that occurred is inherited.

TABLE XL.—*Correlation between yield of plant and percentage of stem-rust infection in F_2 material of the crosses of Kota and Hard Federation wheats grown at St. Paul, Minn., in 1922*

Stem-rust infection, per cent	Yield of plant in grams													Total
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	14.5	15.5	
5	2		1		2	1	2	1						9
15	2	2	7	6	6	4	7	5	1					40
25	4	10	12	15	11	13	10	4	1	3	1	1		85
35	3	14	16	23	14	12	1	2	6	1				92
45	13	27	27	23	25	16	7	7	2		2		1	150
55	1	7	7	9	3	6	6	2	1	1				43
65	3	23	15	15	19	7	8	4	1	1				96
75		4	7	7	4	6	3							31
85	1		4	2	2	2	2	1	1	1				16
95		1	1											2
Total	29	88	97	100	86	67	46	26	13	7	3	1	1	564

$r = -0.082 \pm 0.028$

TABLE XLI.—*Correlation between percentage of stem-rust infection in F_2 and F_3 material of reciprocal crosses of Kota and Hard Federation wheats grown at St. Paul, Minn., and Mandan, N. Dak., in 1922, and at Mandan, N. Dak., in 1923*

Stem-rust infection, 1923 (per cent)	Stem-rust infection, per cent, 1922									Total
	5	15	25	35	45	55	65	75	85	
5		5								5
15	43	74	2	1						120
25	26	91	13	7	6	1	2	1		147
35	6	15	5	8	17	4	6	2		63
45	3	7	9	7	10	6	13	2	3	60
55		1	5	3	1	2	3		2	17
65					4	1	3	2		10
75								1	1	2
Total	78	193	34	26	38	14	27	8	6	424

$r=0.674\pm0.018$

SUMMARY

1. This genetic study was made for the purpose of obtaining resistance to drought and rust in a high-yielding hard red spring wheat of superior milling and bread-making quality.

2. The Kota and Hard Federation varieties were selected as parents for the crosses because they appeared to be the best available material for combining in one study the problems of obtaining resistance to drought and rust, combined with high yield and quality.

3. The material was grown at three points, i. e., Davis, Calif., under ideal conditions, St. Paul, Minn., under conditions of rust prevalence, and Mandan, N. Dak., under droughty conditions.

4. Reciprocal crosses were studied. No important maternal or paternal influence was found although a slight and consistent influence was noted for certain characters. With these, only when the variety with the dominant character was used as the female parent was a fit significantly close to the expected ratio usually obtained.

5. The inheritance of awns was partially explained on a dihybrid Mendelian ratio, in which five classes were studied and the short-awned and awned classes were shown to be recessive to the awnless, apically-awnletted and awnletted classes. Neither the awned nor awnless classes bred true in F_3, and complete homozygosity for these classes could be interpreted only on a multiple-factor hypothesis.

6. Glume color did not appear to be inherited in a monohybrid ratio in F_2, but those data corrected on the basis of F_3, when a part of the recessive white-glumed class segregated, proved that only one genetic factor was involved.

7. The color of the kernel segregated in F_2 in numbers close to the 15:1 ratio. In F_3 the white strains bred true and the red strains bred true or segregated in a 3:1 or 15:1 ratio.

8. Early maturity as determined by date of heading was found to be dominant to late maturity.

9. Tallness of plant appeared to be partially dominant but due principally to heterosis and was easily affected by environmental conditions.

10. Resistance to stem rust proved recessive and in F_2 appeared to occur close to a 1:15 ratio. In F_3, however, not one of nearly 300 resistant F_2 families bred true for resistance, although at St. Paul, Minn., 8.1 per cent of 2,068 F_3 plants were resistant and at Mandan, N. Dak., 23.4 per cent of 6,387 were classed as resistant. Evidence was shown that strains homozygous for resistance could be obtained in F_4.

11. Yield appeared to be due to multiple factors. F_2 hybrids exceeded the parents in variability, but F_3 selections were less variable in comparison with the parents than the F_2 selection.

12. Segregation for quality and quantity of the gluten was shown, by the use of viscosity and crude-protein determinations, to have occurred prior to the F_4.

13. Evidence of segregation for the color and ash of the flour also was indicated among F_4 selections.

14. The amount of correlation between date of heading and height of plant increased with increasingly unfavorable environmental conditions due to rust and drought.

15. A significant positive correlation was found between date of heading and percentage of stem-rust infection; the earlier plants apparently partially escaped rust.

16. Date of heading and yield of plant were negatively correlated, early plants proving more productive. An important correlation was obtained between dates of heading in 1922 and in 1923.

17. Important and significant positive correlations were obtained between yield and height of plant and between heights of plant in 1922 and in 1923.

18. Small positive correlations were found between awn and yield. Differences of 11 to 18 per cent in yield were found in favor of awned over awnless strains.

19. Negative correlations, not important or significant, were obtained between yield of plant and stem-rust infection. An important correlation was obtained between stem-rust infections in 1922 and in 1923, proving that resistance is inherited.

20. Selections have been made from the cross on the basis of the information gained from the investigations. Early, tall, awned, rust-resistant high-yielding plants predominate among the selections. Their quality in F_4 and later generations, based on the quality and quantity of gluten and color and ash of the flour, have been and will be used as a basis for further trial or for elimination. The white types are being grown in the Pacific Coast area and the hard red spring types will be extensively tested under conditions of drought and rust in the northern spring-wheat area.

LITERATURE CITED

(1) ANONYMOUS.
1908. THE PROBABLE ERROR OF A MEAN, BY STUDENT. Biometrica 6: 1–25.

(2) AAMODT, O. S.
1923. THE INHERITANCE OF GROWTH HABIT AND RESISTANCE TO STEM RUST IN A CROSS BETWEEN TWO VARIETIES OF COMMON WHEAT. Jour. Agr. Research 24: 457–469, illus.

(3) BEAVEN, E. S.
1920. BREEDING CEREALS FOR INCREASED PRODUCTION. Jour. Farmers Club, London, pt. 6, p. 107–131.

(4) BIFFEN, R. H.
1905. MENDEL'S LAW OF INHERITANCE AND WHEAT BREEDING. Jour. Agr. Sci. 1: 4–48, illus.

(5) BRYAN, W. E., and PRESSLEY, E. H.
1921. PLANT BREEDING. INHERITANCE OF EARLINESS IN WHEAT. Ariz. Agr. Exp. Sta. Ann. Rpt. (1920/21) 32: 603–605.

(6) CLARK, J. A., MARTIN, J. H., and BALL, C. R.
1922. CLASSIFICATION OF AMERICAN WHEAT VARIETIES. U. S. Dept. Agr. Bul. 1074, 238 p., illus.

(7) ——— and SHOLLENBERGER, J. H.
1924. COMPARATIVE VALUE OF KOTA AND MARQUIS WHEATS FOR MILLING AND BREAD MAKING. Northwestern Miller. (In press.)

(8) ——— STEPHENS, D. E., and FLORELL, V. H.
1920. AUSTRALIAN WHEAT VARIETIES IN THE PACIFIC COAST AREA. U. S. Dept. Agr. Bul. 877, 25 p., illus.

(9) ——— and WALDRON, L. R.
1923. KOTA WHEAT. U. S. Dept. Agr. Circ. 280, 16 p., illus.

(10) ENGLEDOW, F. L., and WADHAM, S. M.
1923. INVESTIGATIONS ON YIELD IN THE CEREALS. I. Jour. Agr. Sci. 13: 390–439, illus.

(11) FARRER, W.
1898. THE MAKING AND IMPROVEMENT OF WHEATS FOR AUSTRALIAN CONDITIONS. Agr. Gaz. N. S. Wales 9: 131–168, 241–260.

(12) FLORELL, V. H.
1923. CEREAL EXPERIMENTS AT CHICO, CALIF. U. S. Dept. Agr. Bul. 1172, 33 p., illus.

(13) ———
1924. STUDIES ON THE INHERITANCE OF EARLINESS IN WHEAT. Jour. Agr. Research. (In press.)

(14) FREEMAN, G. F.
1918. PRODUCING BREADMAKING WHEATS FOR WARM CLIMATES Jour. Heredity 9: 211–226, illus.

(15) GAINES, E. F.
1917. INHERITANCE IN WHEAT, BARLEY, AND OAT HYBRIDS. Wash. Agr. Exp. Sta. Bul. 135, 61 p., illus.

(16) GORTNER, R. A., and SHARP, P. F.
1923. THE PHYSICO-CHEMICAL PROPERTIES OF STRONG AND WEAK FLOURS. III. VISCOSITY AS A MEASURE OF HYDRATION CAPACITY AND THE RELATION OF THE HYDROGEN ION CONCENTRATION TO INHIBITION IN THE DIFFERENT ACIDS. Jour. Phys. Chem. 27: 481–492, illus.

(17) GRANTHAM, A. E.
1918. WHEAT INVESTIGATIONS—VARIETIES. Del. Agr. Exp. Sta. Bul. 121, 49 p., illus.

(18) HARLAN, H. V., and ANTHONY, S.
1920. DEVELOPMENT OF BARLEY KERNELS IN NORMAL AND CLIPPED SPIKES AND THE LIMITATIONS OF AWNLESS AND HOODED VARIETIES. Jour. Agr. Research 19: 431–472, illus.

(19) HAYES, H. K.
1923. INHERITANCE OF KERNEL AND SPIKE CHARACTERS IN CROSSES BETWEEN VARIETIES OF TRITICUM VULGARE. Minn. Stud. Plant. Sci. 4: 163–183.

(20) ——— and AAMODT, O. S.
1923. A STUDY OF RUST RESISTANCE IN A CROSS BETWEEN MARQUIS AND KOTA WHEATS. Jour. Agr. Research 24: 997–1012, illus.

(21) ——— and STAKMAN, E. C.
1922. WHEAT STEM RUST FROM THE STANDPOINT OF PLANT BREEDING. Proc. Ann. Meeting West Canad. Soc. Agron. (1921) 2: 22–35, illus.

(22) HOWARD, A., and HOWARD, G. L. C.
1912–15. ON THE INHERITANCE OF SOME CHARACTERS IN WHEAT. Mem. Dept. Agr. India, Bot. Ser. 5: 1–47, illus., 1912; 7: 273–285, illus., 1915.

(23) LUERS, H., and OSTWALD, W.
1919. BEITRÄGE ZUR KOLLOIDCHEMIE DES BROTES, II. ZUR VISKOSIMETRIE DER MEHLE. Kolloid Ztschr. 25: 82–90.

(24) NILSSON-EHLE, H.
1911. KREUZUNGSUNTERSUCHUNGEN AN HAFER UND WEIZEN, II. Lunds. Univ. Arsskr. N. F., Afd. 2, Bd. 7, No. 6, 82 p.

(25) OSTWALD, W.
1919. BEITRÄGE ZUR KOLLOIDCHEMIE DES BROTES, I. UEBER KOLLOIDCHEMISCHE PROBLEME BEI DER BROTBEREITUNG. Kolloid Ztschr. 25: 26–45.

(26) PERLITIUS, L.
1903. DER EINFLUSS DER BEGRANNUNG AUF DIE WASSERVERDUNSTUNG DER ÄHREN UND DIE KORNQUALITÄT. 77 p., illus. Merseburg. (Inaug. Diss. Breslau.)

(27) SAUNDERS, C. E.
[1907]. THE INHERITANCE OF AWNS IN WHEAT. Rpt. Internat. Conf. Genetics (1906) 3: 370–372, illus.
(28) SCHMID, B.
1898. BAU UND FUNCTIONEN DER GRANNEN UNSERER GETREIDEARTEN. Bot. Centbl. 76: 1–9, 36–41, 70–76, 118–128, 156–166, 212–221, 264–270, 301–307, 328–334, illus.
(29) SHARP, P. F., and GORTNER, R. A.
1923. THE PHYSIO-CHEMICAL PROPERTIES OF STRONG AND WEAK FLOURS. VI. THE RELATION BETWEEN THE MAXIMUM VISCOSITY OBTAINABLE BY THE ADDITION OF LACTIC ACID AND THE CONCENTRATION OF FLOUR-IN-WATER SUSPENSIONS. Jour. Phys. Chem. 27: 771–788, illus.
(30) SHOLLENBERGER, J. H., and CLARK, J. A.
1924. MILLING AND BAKING EXPERIMENTS WITH AMERICAN WHEAT VARIETIES. U. S. Dept. Agr. Bul. 1183, 92. p., illus.
(31) ——— MARSHALL, W. K., and COLEMAN, D. A.
1924. EXPERIMENTAL MILLING AND BAKING. U. S. Dept. Agr. Bul. 1187, 83 p., illus.
(32) SPILLMAN, W. J.
1902. EXCEPTIONS TO MENDEL'S LAW. Science, (n. s.) 16: 792–794.
(33) STAKMAN, E. C., and LEVINE, M. N.
1922. THE DETERMINATION OF BIOLOGIC FORMS OF PUCCINIA GRAMINIS ON TRITICUM SPP. Minn. Agr. Exp. Sta. Tech. Bul. 8, 10 p., illus.
(34) THOMPSON, W. P.
1918. THE INHERITANCE OF THE LENGTH OF THE FLOWERING AND RIPENING PERIODS IN WHEAT. Trans. Roy. Soc. Canada III 12: 69–87.
(35) TSCHERMAK, E. VON
1901. UEBER ZÜCHTUNG NEUER GETREIDERASSEN MITTELST KÜNSTLICHER KREUZUNG. Ztschr. Landw. Versuchsw. Oesterr. 4: 1029–1060.
(36) WALDRON, L. R., and CLARK, J. A.
1919. KOTA, A RUST-RESISTING VARIETY OF COMMON SPRING WHEAT. Jour. Amer. Soc. Agron. 11: 187–195, illus.
(37) WEAVER, H. A., and GOLDTRAP, W. A.
1922. FLOUR STRENGTH. Jour. Amer. Assoc. Cereal Chemists 7: 115–123.

EGG AND FIRST-STAGE LARVA OF TARSOSTENUS UNIVITTATUS (ROSSI), A BEETLE PREDACIOUS ON POWDER-POST BEETLES[1]

By R. A. ST. GEORGE

Assistant Entomologist, Forest Insect Investigations, Bureau of Entomology, United States Department of Agriculture

INTRODUCTION

The family Cleridae has long been recognized as one of considerable economic importance because of the predacious habits of the beetles, both in the larval and adult stages. Champlain (*1*)[2] states that "they are among the principal predators of wood and bark boring beetles, the adults attacking the adults of the destructive species while the larvae feed upon the eggs and broods in the bark and wood." And he continues:

"Under natural conditions they may be of but normal importance but can be turned to considerable account in control measures with the additional help of man, who can overbalance the natural conditions in favor of the predators by properly conducting control work."

The beetle *Tarsostenus univittatus* (Rossi)[3] is one of the clerid species and, according to Champlain (*1*), principally a predator on powder-post beetles such as Lyctus and Xylobiops (=Sinoxylon) in dry, seasoned wood products.[4] Of this species several living adults were obtained while the writer was supervising a series of experiments which were recently conducted by the Bureau of Entomology in cooperation with the Naval Aircraft Factory at the League Island Navy Yard, Philadelphia, Pa., to determine temperatures fatal to the powder-post beetle *Lyctus planicollis* Le Conte by steaming infested ash and oak lumber in a kiln (*5*). Additional infested ash lumber was sent to the Forest Insect Laboratory, East Falls Church, Va., and several adult beetles were secured from this material to be placed in cages for rearing.

TRANSFORMATION TO ADULTS AND MATING

Most of the beetles probably pass the winter in the larval stage, although a few may pupate before early spring, especially if they are in wood which is kept in a heated building. In December, 1923, samples of infested wood were placed in a heated building and were kept at a temperature of 70° F., or slightly higher. When examined five weeks later, most of the beetles were in the larval stage, but two pupæ and three maturing adults were found. This is in accordance with the statement of Champlain (*1*) that "clerids overwinter sometimes in all stages, and sometimes only in a certain stage. The time of transformation to adults is generally in the spring, but it varies." Thus the first adults emerged from the cages containing the infested lumber during the early part of February.

Probably the adults of *Tarsostenus univittatus* emerge about the same time as those of their host, *Lyctus planicollis*, for Snyder (*3*, *p. 14*, *4*) records that adults of the latter emerged as early as January 12 in a heated building in the vicinity of Washington, D. C., that their general appearance occurs about the middle of April, the maximum emergence from the last of April to the first of June, and the last emergence during the first part of July. All these data coincide with corresponding data for *Tarsostenus univittatus*, as far as observations have been made.

The mating usually occurs shortly after the adults emerge.

OVIPOSITION

Oviposition begins a day or two after the adults emerge from the wood and mate. The beetles were observed to crawl into the entrance galleries of their host, and it is likely that eggs were deposited there. According to Champlain (*1*) "they may be placed in or near the entrance gallery of their

[1] Received for publication April 22, 1924—issued—January, 1925.

[2] Reference is made by number (italic) to "Literature cited," p. 51.

[3] Order Coleoptera, family Cleridae.

[4] That the larva does not confine itself to attack on a single host is suggested by the observations of the present writer, who saw a mature larva in rearing crawl over the surface of the wood and enter a gallery of Lyctus from which powderlike borings were being ejected. Altogether, a large percentage of their host must have been killed by the attacks of the beetle, both in the larval and adult stages.

host." In order to observe the process of oviposition three adults, two females and a male, were placed in a small vial which contained a porous stopper. In this way oviposition was observed without much difficulty. The female, before inserting the egg, spends considerable time moving from place to place, with the ovipositor extended, to find a suitable opening. The ovipositor is nearly as long as the body. It terminates in two slender, palpilike processes which are used to locate the desired opening. When such a place has been found the end of the body is placed close to the opening and the ovipositor is inserted into the cavity.

THE EGG

The egg (fig. 1, *a*), in many respects, bears a rather striking resemblance to that of its host, *Lyctus planicollis* (fig. 1, *b*). In fact, when seen in a pore in the wood, it might easily be mistaken for the latter. It (fig. 1, *d*) is elongate, cylindrical, rounded at the posterior end and drawn out into a slender strandlike process at the cephalic end. It is grayish-white in color, somewhat shiny, 0.85 mm. long without the strandlike process, or 1.2 mm. with this process included, and 0.123 mm. in width. The egg of *Lyctus planicollis* is slightly smaller, being 1 mm. long with

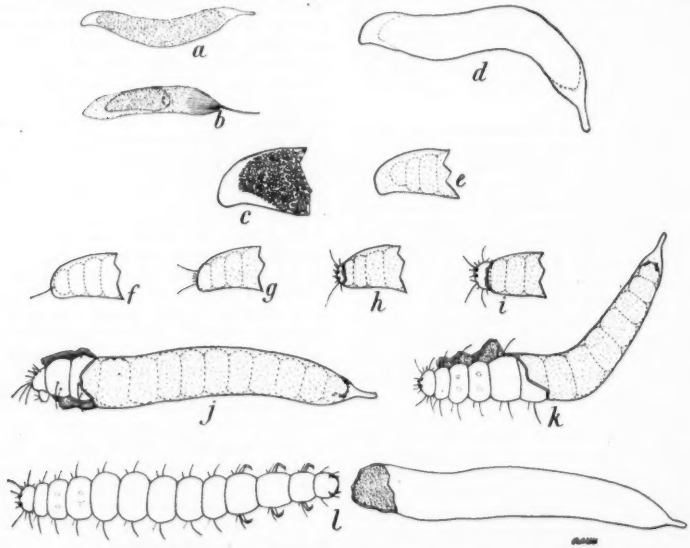


FIG. 1.—*Tarsostenus univittatus: a*, Egg with newly formed embryo; *c*, greatly enlarged view of end of egg, showing granular appearance; *d*, outline of egg, showing strandlike attachment; *e*, part of egg, showing dorsal view of 6th, 7th, 8th, and 9th abdominal segments of larva ready to hatch; *f–k*, larva hatching from egg, liberating first the caudal setae and then the abdominal segments; *l*, larva free from eggshell, and the empty shell. *Lyctus planicollis: b*, Egg with larva ready to hatch, drawn to same scale as *a*.

After a short time, during which a pumping movement was noted in the ovipositor, the egg was inserted into the pore. In one instance seven minutes elapsed before the process of ovipositing was completed. Upon examining the stopper three days later seven eggs were found. They were all inserted in the same cavity, side by side, probably for the simple reason that it was the most favorable place. It is quite likely that under natural conditions from one to three eggs would be deposited in a pore, as is the case with Lyctus.

the process (fig. 1, *b*). The process resembles that on the eggs of *Lyctus planicollis*, and of the bostrychids *Scobicia declivis* Lec. (*2*) and *Xylobiops basilaris* (Say). It has a granular appearance (fig. 1, *c*) like that of Lyctus but differs from the latter by the absence of the longitudinal striae on the end which bears the process. As is the case with the above mentioned eggs which it resembles, the end bearing the strandlike process leaves the ovipositor last.

After the egg is a few days old the formation of the larva within can be

seen, especially when the latter moves. It occupies nearly the entire egg. After a period of incubation of about 10 days the larva becomes quite active and is ready to emerge. It twists and turns, causing the closely-fitting eggshell to follow the movements of its body. At that time, just before hatching, part of the segments assume a violet tint and the mandibles can now be seen.

The process of hatching is a very interesting one and is accomplished in a manner which again is similar to what we find in *Lyctus planicollis* (fig. 1, *e–l*).

When ready to emerge, the larva begins to push against the posterior end of the egg by alternately contracting and expanding its body (fig. 1, *e*). The ninth abdominal segment is armed with stiff setae which are used for piercing the eggshell. First one (fig. 1, *f*) and then several setae may be seen protruding through the end of the shell (fig. 1, *g*). Next, the abdominal segments may be seen gradually working themselves out (fig. 1, *h–k*), until finally the larva frees itself completely and starts to crawl about (fig. 1, *l*).

Under natural conditions the entire process of emerging probably takes less than an hour, but in the laboratory, when the eggs were placed in a plaster cell and little opportunity given for holding the shell in place, it took three hours. When, however, the cephalic end of the shell was held fast the process was completed in considerably less time. From this fact it occurred to the writer that the reason why eggs of this type have the peculiar strandlike process at the cephalic pole is that it enables the adult to attach the strand to the wood in order that the egg can be held in place while the larva emerges. In one instance a larva was unable to emerge from the egg after twisting and turning for a long time, presumably owing to the fact that the egg was not held in place.

THE FIRST-STAGE LARVA

The first-stage larva is armed with setae which are much longer than in the mature specimens.[5] When the larva is in the egg these setae are pressed close to the body, but as soon as the segments are free from the eggshell the setae straighten out. The newly hatched larva is nearly white except for the violet markings on the segments; the ampullae are slightly developed on the terga of the 6th and 7th abdominal segments, a characteristic also of the mature larva. The mandibles, cerci, and claws are lightly chitinized, and four ocelli are present on each side of the head, also as in the mature larva. It has not been possible to find any spiracles.

SUMMARY

Tarsostenus univittatus (Rossi) belongs to the family Cleridae, which is of considerable economic importance because of the predacious habits of the beetles in both the larval and adult stages. Several adults were reared from ash lumber infested with the powder-post beetle *Lyctus planicollis* Le Conte, on which it is known to be predacious.

Under normal conditions the beetles pass the winter in the larval stage and adults emerge in the spring about the time the powder-post beetles appear.

Oviposition begins soon after the adults mate; elongate, cylindrical, grayish-white eggs, which possess a peculiar strand-like process on the cephalic end, are deposited in or near the entrance gallery of their host. The process is probably attached to the wood to hold the eggshell in place while the larva emerges. After a period of incubation of about 10 days, the larva hatches from the egg by backing out, freeing itself by using its long, stiff caudal setae to pierce and break the posterior end of the shell.

The first-stage larva differs from the mature form in that the setae are much longer, but resembles it in having violet-colored markings on its segments; ampullae present on the sixth and seventh terga; the mandibles, claws, and cerci lightly chitinized; and four ocelli on each side of the head.

LITERATURE CITED

(1) BÖVING, A. G., and CHAMPLAIN, A. B.
1920. LARVAE OF NORTH AMERICAN BEETLES OF THE FAMILY CLERIDAE. Proc. U. S. Nat. Mus. 57: 575–649.

(2) BURKE, H. E., HARTMAN, R. D., and SNYDER T. E.
1922. THE LEAD-CABLE BORER OR "SHORT-CIRCUIT BEETLE" IN CALIFORNIA. U. S. Dept. Agr. Bul. 1107, 56 p., illus.

(3) HOPKINS, A. D., and SNYDER, T. E.
1917. POWDER-POST DAMAGE BY LYCTUS BEETLES TO SEASONED HARDWOOD. Farmers' Bul. 778, U. S. Dept. Agr., 20 p., illus.

(4) SNYDER, T. E.
1916. EGG AND MANNER OF OVIPOSITION OF LYCTUS PLANICOLLIS. Jour. Agr. Research 6: 273–276, illus.

(5) SNYDER, T. E., and ST. GEORGE, R. A.
1924. DETERMINATION OF TEMPERATURES FATAL TO THE POWDER-POST BEETLE LYCTUS PLANICOLLIS LE CONTE BY STEAMING INFESTED ASH AND OAK LUMBER IN A KILN. Jour. Agr. Research 28: 1133–1138, illus.

[5] A. G. Böving (*1*) has described and figured the mature larvae of this family.

PYTHIUM ROOTLET ROT OF SWEET POTATOES[1]

By L. L. HARTER

Pathologist, Office of Cotton, Truck, and Forage Crop Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture

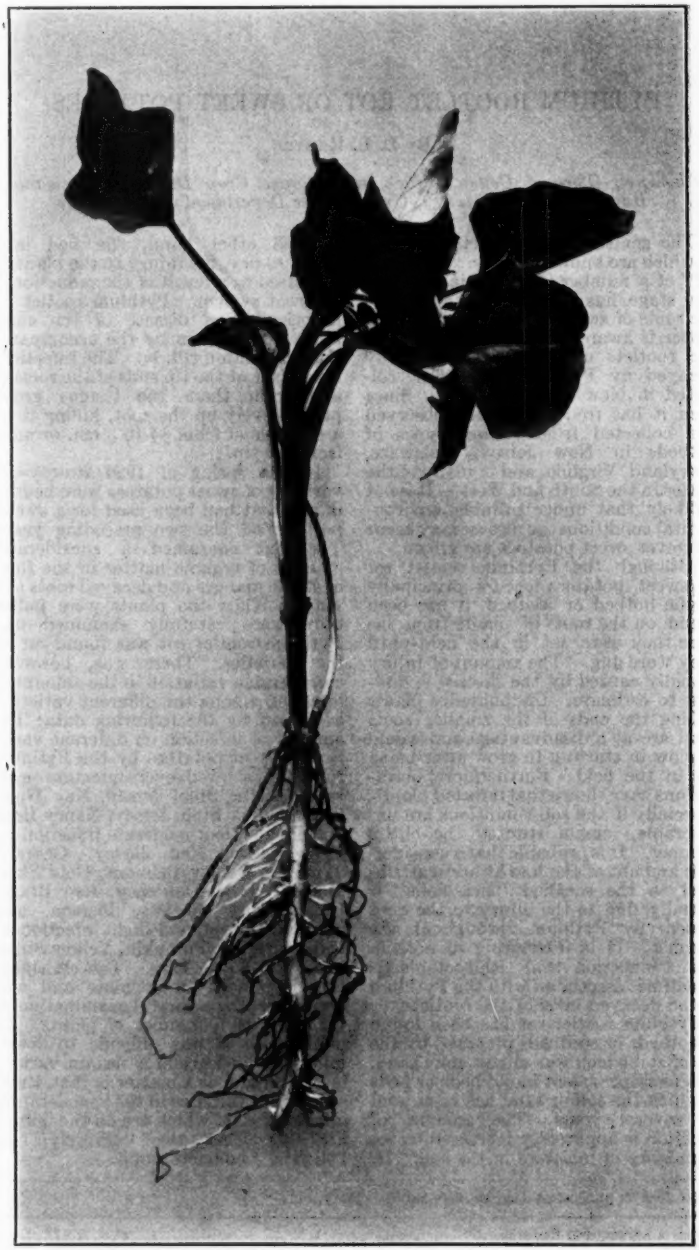
The genus Pythium, certain species of which are known to cause "damping-off" of a number of plants in the seedling stage, has never been reported on the roots of sweet potatoes so far as the writer is aware. Sweet potato plants, the rootlets of which were partially decayed by Pythium, were first collected in New Jersey in 1914. Since then it has frequently been observed and collected from various types of hotbeds in New Jersey, Delaware, Maryland, Virginia, and in many of the States in the South and West. It is not unlikely that under suitable environmental conditions the disease may occur wherever sweet potatoes are grown.

Although the Pythium rootlet rot of sweet potatoes occurs principally in the hotbed or seedbed, it has been found on the roots of plants from the time they were set in the field until they were dug. The amount of injury actually caused by the disease is difficult to estimate. Undoubtedly plants having the ends of the smaller roots dead are at a disadvantage and would be slow in starting to grow after being set in the field. Furthermore, observations have shown that infected plants, especially if the soil conditions are unfavorable, remain stunted the entire summer. It is probable that a considerable amount of the loss hitherto attributed to the socalled "sick soils" is actually due to the injury to the root system by Pythium throughout the summer. It is interesting to note in this connection that Rhizoctonia is sometimes associated with the Pythium in the decayed ends of the rootlets.

Pythium rootlet rot has been found in hotbeds or seedbeds prepared by the use of soil which was almost pure sand. It is more prevalent in old beds or beds in which the soil or sand has been used for several years. The amount of infection is apparently increased by an abundance of moisture in the soil. If, on the other hand, the bed later becomes dry, the injury to the plants is increased as a result of the reduction of the root system. Pythium rootlet rot is primarily a disease of the small rootlets, as shown by the accompanying illustration (Pl. 1). The infections take place at the tip ends of the rootlets and from there the fungus grows progressively up the root, killing it for a distance of from ½ to 3 cm. or more from the tip.

In the spring of 1924 twenty-one varieties of sweet potatoes were bedded in soil that had been used for a sweet-potato bed the two preceding years. The soil contained a considerable amount of organic matter in the form of stable manure and decayed roots and vines. When the plants were pulled they were carefully examined and Pythium rootlet rot was found on all the varieties. There was, however, considerable variation in the amount of infection among the different varieties, as shown by the following data: The amount of infection on different varieties of sweet potatoes by the Pythium rootlet rot showed severe infection on six varieties, Big Stem Jersey, Key West, Creola, Little Stem Jersey, Nancy Hall, and Porto Rico; moderate infection on 12 varieties, Red Jersey, Georgia, Triumph, Yellow Belmont, Gold Skin, Dooley, Haiti, Dahomey, Red Brazil, Gen. Grant Vineless, Pierson, and Southern Queen; and slight infection on three varieties, Pumpkin, Yellow Strasburg, and White Yam. This classification is merely an estimate and was determined by a careful examination of the roots of a number of plants. In many cases it was difficult to determine to which group a certain variety belonged, and as a matter of fact, there are several varieties in the "moderately infected" class which are on the border line of either the "severely" or "slightly" infected group.

[1] Received for publication Aug. 30, 1924—issued January, 1925.



Pythium Rootlet Rot of Sweet Potatoes Plate 1

Note the large number of rootlets that are partially or completely decayed. Infection usually begins at the end of the rootlet and extends progressively up the root

The writer has made no study of the species causing Pythium rootlet rot. The taxonomy of the causal organisms will be handled by Dr. Chas. Drechsler, who is making a monographic study of the genus. Judging from a preliminary study of the large number of cultures Doctor Drechsler has already obtained from the sweet-potato roots, it is not unlikely that two or three species of the *debaryanum* type may be identified.

SUMMARY

The Pythium rootlet rot of sweet potatoes occurs quite commonly in the hotbeds in various parts of the country. The disease apparently has its beginning at the end of the small rootlets and works progressively up the root. Investigations have shown that all 21 varieties tested are susceptible to the disease, but not to the same degree.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
SUBSCRIPTION PRICE, $4.00 PER YEAR (DOMESTIC)
$5.25 PER YEAR (FOREIGN)

▽